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metrex instruments limited

201 Wilkinson Road, Brampton, Ontario L6T 4M2 Telephone: (416) 453-1110

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DIESEL/MINERAL SENSOR FINAL REPORT

Submitted to:

Mr. G. Knight
Scientific Authority
Mining Research Laboratory
Elliot Lake, Ontario

Submitted by:

Metrex Instruments Ltd.
201 Wilkinson Road
Brampton, Ontario
L6T 4M2

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1. INTRODUCTION

Suspended particulate matter in mines originates primarily from breaking of the rock and from the operation of diesel engines and pneumatic equipment. The rock-breaking activities result in the generation of a polydispersed particulate matter with a size distribution ranging from a fraction of a micrometre up to millimetres. Large particles will sediment out of the air, while the particles of a small size fraction remain suspended and constitute a health hazard.

The health hazard curve as presented e.g. in Mercer (1973), defines as most dangerous the particles in the range between 0.5 and 5 µm. There are still open questions related mainly to the importance of small particles under 0.5 µm. The health hazard curve is constructed from the frequency of particles found in the lung tissue of deceased miners by optical microscopy. More accurate methods might reveal that mineral particles under 0.5 µm also constitute a health hazard.

Diesel exhaust particulates are a relatively recent concern. They are spherical, of a size around 0.05 µm, sometimes agglomerated into randomly shaped or elongated clusters. Soot particles are often covered with a layer of unburned hydrocarbons or by other condensed substances, accumulated in the process of expansion and dilution of the gas emitted from the engine. An important component

of the mine atmosphere is the oil mist, dispersed by the moving components of pneumatic machinery. The liquid oil particles are mostly under 1 um in size, exactly spherical due to the action of surface tension.

G. Knight et at (1982, 1981, 1980) presented detailed size distribution and concentrations of airborne particles encountered in the mine both for the mineral and diesel components. The concentrations of diesel exhaust particulates and oil mist are around 1 mg/m^3, while the highest values found for mineral dust are approx. 0.2 mg/m^3.

The concentration, size distribution and composition of airborne particulates in the mine can be presently established by the technique of filter trapping and subsequent analysis by laboratory methods.

The requirements of industrial hygiene would be satisfied better by an "in situ" type of technique that would have an instant response and thus allow to monitor variations of dust loading in time and space as related to particular activities. The technique must be capable of distinguishing between the two major classes of airborne particles of interest, mineral dust and diesel exhaust.

It has been suggested that the mineral dust and diesel fumes could be distinguished on the basis of their distinctly

different particle size distribution. Mineral dust of interest ranges from 0.5 to 6 or 10 μm, while diesel exhaust peaks well under 0.5 μm.

In addition to the light scattering technique of aerosol detection for mineral and diesel components, we have investigated theoretically and experimentally the ionization technique for the detection of diesel fumes.

The smoke ionization method utilizes a small radioactive source ionizing the air molecules located in a sensing chamber. The ions then form a current between two electrodes. Dust or diesel exhaust particles attach themselves to the ions, slow them down and reduce the current. The technique has a maximum sensitivity to small particles and is well suited for the size range of diesel fumes. However, our experiments have shown that the technique is highly sensitive to air motion. The air flow blows the ions out of the sampling volume thus decreasing the current and causing large reading errors. As a result, the technique would be usable only if the air flow were strictly controlled by a small pump, which would complicate the system. The present concept of the instrument is based on the utilization of natural diffusion and drafts for bringing the air into the sample volume of the instrument.

An alternative method for measurement of diesel fumes is the utilization of light scattering, that has established its usefulness in the measurement of a respirable mineral dust. To distinguish between diesel fumes and mineral dust the system must operate at two different light scattering geometries, possibly in a time sharing mode, so that the differences in size distributions of the two particulate clouds would be detected from the differences in their angular scattering pattern. The optical system designed to detect mineral dust will receive the scattering light primarily in the forward direciton while the system for monitoring diesel fumes will collect light on scattering directions close to 90^{o}. The optimization of the light scattering geometry can be done numerically by the use of computer subroutines for the MIE scattering or for the Fraunhofer approximation, well applicable to forward scattering. The workers of Ford Motor Company and General Motors (Japar, 1981) described the measurement of diesel fume concentrations in a dilution wind tunnel utilizing both the classical method of filter trapping and the optical extinction of a laser beam. The resulting coefficient of optical extinction they provided correlates well with the filter measurement, within several per-cent regardless of the exact history of fume formation, condensation and dilution. It indicates that optical method in

general can be used to express the concentration of diesel fumes, with a reasonable degree of reproducibility. The optical light scattering technique has also the advantage of its "in-situ" character and an instant response. Its accuracy will be continuously improved as the experience from actual mine measurements is accumulated.

A microprocessor-based technique of signal recording, analysis and logging will provide not only an instant display, but also an analog output and a one-week store of data that can be discharged into a printer after each shift or weekly. In order to monitor dust concentrations in a number of points in the mine, the instrument will be designed as simple and inexpensive as possible with an internal battery and low-power electronics.

2. LIGHT SCATTERING ON PARTICLES

To analyze the capability of a scattering instrument to distinguish between diesel exhaust particulates and mineral dust we shall compare the response to particle size of different geometries of the sensor.

An illuminated particle (Fig. 1) scatters light into the entire solid angle of 4π. The intensity of scattered light is

$$i = i_o \cdot i\ (\theta, m, \alpha) \qquad (1)$$

where i_o = intensity of illumination

$i(\theta, m, \alpha)$ = a function described for spherical particles by MIE theory, available in a form of computer subroutines. In the forward scattering direction it can be approximated by the Fraunhofer diffraction, especially for larger and absorbing particles.

θ = scattering angle

m = refractive index of particle

α = size parameter $\alpha = \pi \cdot d/\lambda$

d = particle diameter

λ = wavelength

The scattered light flux received by a detector is

$$E = i_o \int_V \int_\Omega i\ (\theta, m, \alpha)\ d\Omega dV \qquad (2)$$

where Ω = solid angle from which the scattered light is collected

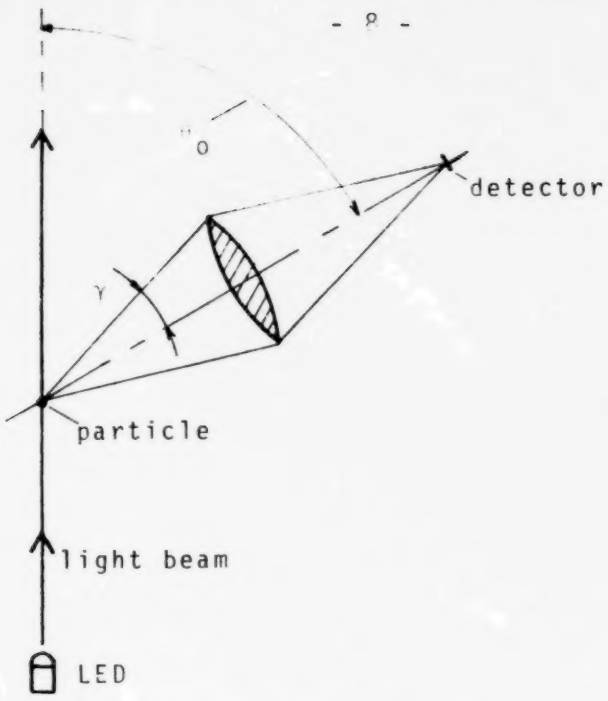


Fig. 1

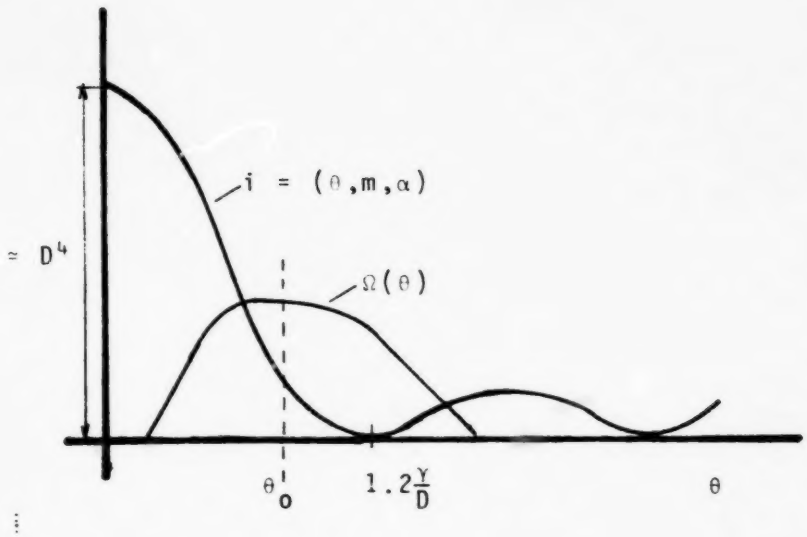


Fig. 3

V = sample volume filled by illuminated particles visible by the detector.

To solve equation (2), it is necessary to specify the relation between the solid angle Ω and the scattering angle θ, from the geometry shown in Fig. 2.

A single beam illuminates a particle located in the centre of a sphere of radius R = 1. The detector lens is represented by a circle of radius γ around the detector axis. The detector is placed at a mean scattering angle θ_o in relation to the direction of illumination.

The element of solid angle $d\Omega$ can be expressed as

$$d\Omega = \frac{2\Delta}{2\pi} \cdot \frac{2\pi R^2 \cdot \sin\theta \cdot d\theta}{R^2} = 2\Delta \sin\theta d\theta \qquad (3)$$

where R = sphere radius, R = 1

Δ = angle shown in Fig. 2.

The angle Δ can be computed from the spherical triangle (crosshatched in Fig. 2) with the sides θ, θ_o and γ:

$$\sin^2\frac{\Delta}{2} = \frac{\sin(s-\theta)\ \sin(s-\theta_o)}{\sin\theta \cdot \sin\theta_o} \qquad (4)$$

where

$$s = \frac{1}{2}(\theta + \theta_o + \gamma) \qquad (5)$$

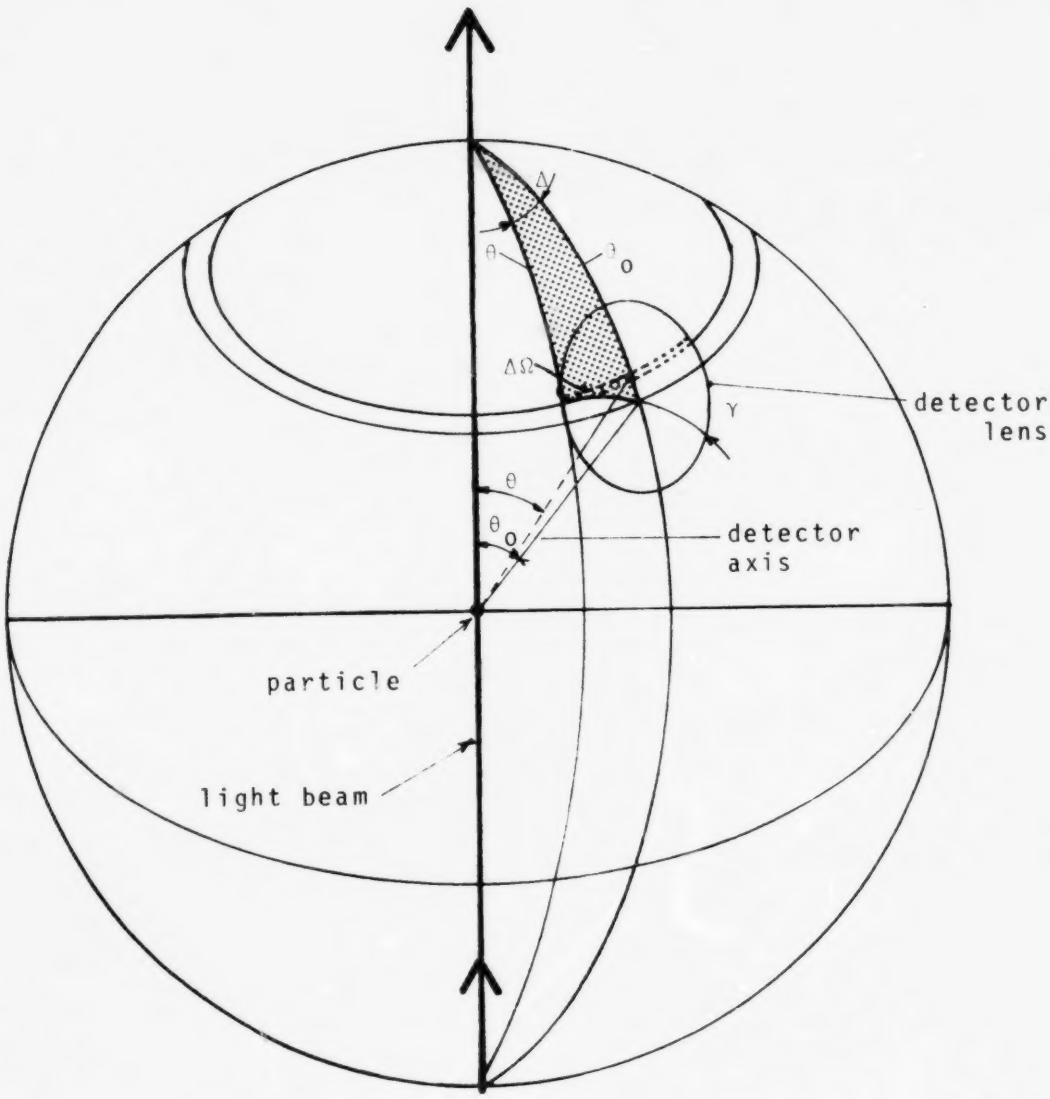

Δγ
θ
θ o
ΔΩ
γ
detector
lens
θ
θ o
detector
axis
particle
light beam

Fig. 2

```
 10 'load: D/M
 20 ' response of diesel/mineral monitor
 30 'Oct 1984
 40 'computes signal from suspended particulates for anLED with divergence of 7 d
 50 'all dimensions in mm,size and lambda in micrometers
 50 'and for a range of lambda 60 nm
 60 'all dimensions in mm,size and lambda in micrometers
 70 '-----------------------------------------------------
 80 '-----------------------------------------------------
 90 F$="     #.###        #.##^^^^         #.##^^^^          #.##^^^^     "
 100 DIM INTENSITY(250),DISTRIBUTION(250),RESPONSE(250)
 110 DIM DIA(11),THETA(250)
 120 THNUL=1.57
 130 GM=.32' num.aperture
 140 DIA(1)=.25:DIA(2)=.5:DIA(3)=.75:DIA(4)=1:DIA(5)=2:DIA(6)=3
 150 DIA(7)=4:DIA(8)=5:DIA(9)=6:DIA(10)=8:DIA(11)=10
 160 PRINT"-----------------------------------------"
 170 PRINT"    theta        intensity    distrib.function     response "
 180 I1=INT((THNUL-.4)*100)
 190 I2=INT((THNUL+.4)*100)
 200 '-----------------------------------------------------
 210 'instrument distrib. function
 220 FOR I=I1 TO I2
 225 THETA(I)=.01*I
 226 THETA=THETA(I)
 230 DISTRIBUTION(I)=0
 240 FOR J=-3 TO 3
 250 THET0=THNUL+.02*J
 260 IF THETA<THET0-GM THEN GOTO 330
 270 IF THETA >THET0+GM THEN GOTO 330
 280 S=(THETA+THET0+GM)/2
 290 SN=SQR(ABS(SIN(S-THETA)*SIN(S-THET0)/(SIN(THETA)*SIN(THET0))))
 300 DEL=2*(ATN(SN/SQR(1-SN*SN)))
 310 DISTRIB=2*DEL*SIN(THETA)
 320 GOTO 340
 330 DISTRIB=0
 340 DISTRIBUTION(I)=DISTRIBUTION(I)+DISTRIB/7
 350 NEXT J
 370 NEXT I
 380 'scattering in the forward lobe.Ref:Abramowitz/Stegun
 390 'scattering intensity computed for K sizes
 400 '-----------------------------------------
```

```
410 FOR k=1 TO 11
420 SUM=0
430 D=DIA(K)                                                    P2
440 FOR I=11 TO 12
445 THETA=THETA(I)
450 INTENSITY(I)=0
470 FOR L=0 TO 2
480 LAMBDA=.91+.03*L
490 SIZE=3.14159*D/LAMBDA
500 X=SIZE*SIN(THETA)
510 IF X<3 THEN GOTO 570
520 Z=3/X
530 F1=.79788+1.56E-06*Z+.01659*Z^2+.000171*Z^3-.002495*Z^4+.0011365*Z^5
540 O1=X-2.35619+.125*Z+.0000565*Z^2-.0063788*Z^3+7.4348E-04*Z^4+7.9824E-04*Z^5-
2.9166E-04*Z^6
550 JX=F1*COS(O1)/X^1.5
560 GOTO 590
570 Y=X/3
580 JX= .5-.5625*Y^2+.210936*Y^4-.03954*Y^6+.0044332*Y^8-.0003176*Y^10+.0000111*
Y^12
590 INTENS=SIZE*JX^2
595 'INTENS represents the scattered intensity per unit particle volume
600 INTENSITY(I)=INTENSITY(I)+INTENS/3
610 NEXT L
620 '-------------------------------------------------------
630 RESPONSE(I)=INTENSITY(I)*DISTRIBUTION(I)
640 IF(-1)^I>0 THEN GOTO 660
650 PRINT USING F$;THETA(I),INTENSITY(I),DISTRIBUTION(I),RESPONSE(I)
660 SUM=SUM+RESPONSE(I)
670 NEXT I
680 PRINT"-------------------------------------------------------"
690 LPRINT " for size D="D"um,scattering dir="THNUL" TOTAL RESPONSE = "SUM
700 PRINT"-------------------------------------------------------"
710 NEXT K
720 END
```

theta	intensity	distrib.function	response
0.290	0.21E+00	0.00E+00	0.00E+00
0.310	0.21E+00	0.00E+00	0.00E+00
0.330	0.21E+00	0.17E-01	0.34E-02
0.350	0.20E+00	0.46E-01	0.94E-02
0.370	0.20E+00	0.85E-01	0.17E-01
0.390	0.20E+00	0.13E+00	0.27E-01
0.410	0.20E+00	0.18E+00	0.38E-01
0.430	0.20E+00	0.24E+00	0.50E-01
0.450	0.20E+00	0.31E+00	0.63E-01
0.470	0.20E+00	0.36E+00	0.73E-01
0.490	0.20E+00	0.41E+00	0.81E-01
0.510	0.20E+00	0.44E+00	0.89E-01
0.530	0.20E+00	0.48E+00	0.95E-01
0.550	0.20E+00	0.51E+00	0.10E+00
0.570	0.20E+00	0.53E+00	0.11E+00
0.590	0.20E+00	0.56E+00	0.11E+00
0.610	0.20E+00	0.58E+00	0.11E+00
0.630	0.20E+00	0.60E+00	0.12E+00
0.650	0.20E+00	0.61E+00	0.12E+00
0.670	0.20E+00	0.63E+00	0.12E+00
0.690	0.19E+00	0.64E+00	0.12E+00
0.710	0.19E+00	0.64E+00	0.12E+00
0.730	0.19E+00	0.65E+00	0.13E+00
0.750	0.19E+00	0.65E+00	0.12E+00
0.770	0.19E+00	0.65E+00	0.12E+00
0.790	0.19E+00	0.64E+00	0.12E+00
0.810	0.19E+00	0.63E+00	0.12E+00
0.830	0.19E+00	0.62E+00	0.12E+00
0.850	0.19E+00	0.60E+00	0.11E+00
0.870	0.19E+00	0.58E+00	0.11E+00
0.890	0.19E+00	0.55E+00	0.10E+00
0.910	0.19E+00	0.52E+00	0.97E-01
0.930	0.19E+00	0.47E+00	0.89E-01
0.950	0.19E+00	0.42E+00	0.77E-01
0.970	0.19E+00	0.33E+00	0.62E-01
0.990	0.18E+00	0.26E+00	0.48E-01
1.010	0.18E+00	0.19E+00	0.34E-01
1.030	0.18E+00	0.12E+00	0.23E-01
1.050	0.18E+00	0.69E-01	0.13E-01
1.070	0.18E+00	0.25E-01	0.46E-02
1.090	0.18E+00	0.00E+00	0.00E+00

for size D= .25 um,scattering dir= .7 TOTAL RESPONSE = 6.166012

0.290	0.39E+00	0.00E+00	0.00E+00
0.310	0.39E+00	0.00E+00	0.00E+00
0.330	0.39E+00	0.17E-01	0.64E-02
0.350	0.38E+00	0.46E-01	0.18E-01
0.370	0.38E+00	0.85E-01	0.32E-01
0.390	0.38E+00	0.13E+00	0.50E-01
0.410	0.37E+00	0.18E+00	0.69E-01
0.430	0.37E+00	0.24E+00	0.90E-01
0.450	0.37E+00	0.31E+00	0.11E+00
0.470	0.36E+00	0.36E+00	0.13E+00
0.490	0.36E+00	0.41E+00	0.14E+00
0.510	0.35E+00	0.44E+00	0.16E+00
0.530	0.35E+00	0.48E+00	0.17E+00

for a range of mean theta=6 deg

theta	intensity	distrib.function	response
0.250	0.11E+04	0.00E+00	0.00E+00
0.270	0.12E+03	0.00E+00	0.00E+00
0.290	0.15E+03	0.00E+00	0.00E+00
0.310	0.66E+03	0.00E+00	0.00E+00
0.330	0.66E+03	0.12E+00	0.76E+02
0.350	0.21E+03	0.32E+00	0.69E+02
0.370	0.86E+00	0.59E+00	0.51E+00
0.390	0.19E+03	0.92E+00	0.17E+03
0.410	0.36E+03	0.13E+01	0.47E+03
0.430	0.25E+03	0.17E+01	0.42E+03
0.450	0.42E+02	0.22E+01	0.91E+02
0.470	0.18E+02	0.25E+01	0.45E+02
0.490	0.14E+03	0.28E+01	0.41E+03
0.510	0.20E+03	0.31E+01	0.63E+03
0.530	0.12E+03	0.33E+01	0.39E+03
0.550	0.14E+02	0.35E+01	0.50E+02
0.570	0.16E+02	0.37E+01	0.58E+02
0.590	0.90E+02	0.39E+01	0.35E+03
0.610	0.13E+03	0.40E+01	0.51E+03
0.630	0.80E+02	0.42E+01	0.33E+03
0.650	0.16E+02	0.43E+01	0.67E+02
0.670	0.36E+01	0.44E+01	0.16E+02
0.690	0.44E+02	0.44E+01	0.20E+03
0.710	0.80E+02	0.45E+01	0.36E+03
0.730	0.72E+02	0.45E+01	0.33E+03
0.750	0.32E+02	0.45E+01	0.14E+03
0.770	0.21E+01	0.45E+01	0.95E+01
0.790	0.78E+01	0.45E+01	0.35E+02
0.810	0.36E+02	0.44E+01	0.16E+03
0.830	0.56E+02	0.43E+01	0.24E+03
0.850	0.51E+02	0.42E+01	0.21E+03
0.870	0.27E+02	0.41E+01	0.11E+03
0.890	0.52E+01	0.39E+01	0.20E+02
0.910	0.84E+00	0.36E+01	0.31E+01
0.930	0.14E+02	0.33E+01	0.46E+02
0.950	0.32E+02	0.29E+01	0.92E+02
0.970	0.41E+02	0.23E+01	0.96E+02
0.990	0.37E+02	0.18E+01	0.67E+02
1.010	0.23E+02	0.13E+01	0.31E+02
1.030	0.87E+01	0.86E+00	0.75E+01
1.050	0.60E+00	0.48E+00	0.29E+00
1.070	0.18E+01	0.18E+00	0.33E+00
1.090	0.10E+02	0.00E+00	0.00E+00
1.110	0.21E+02	0.00E+00	0.00E+00
1.130	0.28E+02	0.00E+00	0.00E+00
1.150	0.31E+02	0.00E+00	0.00E+00

for size D= 10 um,and for direction= .7 THE TOTAL RESPONSE = 12535.17

For a constant aperture γ of the detector system and for a fixed main scattering direction θ_o, Eqs. (3), (4), and (5) allow to express the frequency distribution of the solid angle of detection as a function of the scattering angle θ. We can symbolically rewrite Eq. (2) as

$$E = i_o \cdot V \int_{\theta} i(\theta,m,\alpha) \cdot \Omega(\theta) \cdot d\theta \qquad (6)$$

where $\Omega(\theta)$ = distribution function of solid angle

V = sample volume, assuming the light from each point within V propagates into the same geometry.

Eq. 6 allows to compute the received scattered light by the integration of a product of two functions of the scattering angle θ:

- $i(\theta,m,\alpha)$ a function of the particle only, and
- $\Omega(\theta)$ a function of the instrument geometry only.

Fig. 3 represents grafically the functions $i(\theta)$ and $\Omega(\theta)$. It is well known that large particles scatter light primarily in the forward direction, as expressed by the position of the first minimum of the scattering function

$$\theta_{min} = 1.22 \frac{\lambda}{D} \qquad (7)$$

where λ = wavelength

and D = particle diameter.

Also, the intensity of the scattered light in the direction $\theta = 0$ is proportional to D^4. Thus, for larger particles the forward lobe becomes narrower and higher.

The instrument function $\Omega(\theta)$ is centred around an angle θ_0, representing either a forward scatter (with θ_0 ranging from 0.4 to 0.7 but always $\theta_0 > \gamma$), or a side scatter with $\theta_0 = 1.57$ rad.

3. NUMERICAL RESULTS

Figs P1 - P2 show a copy of the program*. Statements 120 and 130 specify the mean scattering angle θ_0 = THNUL and detector lens aperture γ = GM. Statements 140 and 150 represent the particle diameters for which the computation is repeated.

The distribution function $\Omega(\theta)$ = DISTRIBUTION(I) is computed in 230 to 340, using Eqs. (3), (4) and (5).

Symbols are s = S

θ = THETA (I)

Δ = DEL

To account for a divergence of the LED and for a finite sample space, the computation is repeated for a range of θ_0 between (THNUL - 0.06) and (THNUL + 0.06) rad. The resulting DISTRIBUTION(I) function is an average of the (seven) shifted function DISTRIB.

*) IBM PC BASIC.

The light scattering function $i(\theta)$ = INTENSITY(I) is computed in statements 450 to 600. To account for a finite bandwidth of the LED, the computation is repeated for several wavelengths in the range of 0.91 to 0.97 µm.

In 490: SIZE = $\alpha = \pi \cdot D/\lambda$

In 500: the parameter of the Bessel function J_1 is computed

$$x = \alpha \cdot \sin(\theta) \tag{8}$$

In the Fraunhofer approximation the light scattered from a particle is expressed as

$$i(\theta,\alpha) = C \cdot \alpha^4 \frac{J_1^2(x)}{x^2} \tag{9}$$

In statement 510 to 580 the function $i(\theta)$ is computed using a development of the Bessel function into series given by Abramowitz, Stegun (1975)

In 590 the scattering intensity from Eq. (9) is divided by α^3, representing the particle volume. Thus the resulting $i(\theta)$ represents the scattered light per unity particle concentration (ml of dust per ml of air).

In 630 RESPONSE = $dE = i(\theta) \cdot \Omega(\theta) d\theta$

The SUM or TOTAL RESPONSE is $\Sigma dE = E$, representing the light flux reaching the detector, in arbitrary units.

Fig. P3 is an example of a printout showing $i(\theta)$ = intensity, $\Omega(\theta)$ = distrib. function, and response = $i(\theta) \cdot \Omega(\theta)$ vs theta, for a given size D and θ_o. The total response is the detector light flux E.

```
for size D= .25 um,scattering dir= .4  TOTAL RESPONSE =  6.436777
for size D= .5 um,scattering dir= .4  TOTAL RESPONSE =  11.65849
for size D= .75 um,scattering dir= .4  TOTAL RESPONSE =  14.87707
for size D= 1 um,scattering dir= .4  TOTAL RESPONSE =  15.95492
for size D= 2 um,scattering dir= .4  TOTAL RESPONSE =  10.3132
for size D= 3 um,scattering dir= .4  TOTAL RESPONSE =  6.387126
for size D= 4 um,scattering dir= .4  TOTAL RESPONSE =  4.173388
for size D= 5 um,scattering dir= .4  TOTAL RESPONSE =  2.896984
for size D= 6 um,scattering dir= .4  TOTAL RESPONSE =  2.113078
for size D= 8 um,scattering dir= .4  TOTAL RESPONSE =  1.263541
for size D= 10 um,scattering dir= .4  TOTAL RESPONSE =  .8369668


for size D= .25 um,scattering dir= .5  TOTAL RESPONSE =  6.355107
for size D= .5 um,scattering dir= .5  TOTAL RESPONSE =  11.07882
for size D= .75 um,scattering dir= .5  TOTAL RESPONSE =  13.25723
for size D= 1 um,scattering dir= .5  TOTAL RESPONSE =  12.99347
for size D= 2 um,scattering dir= .5  TOTAL RESPONSE =  5.253564
for size D= 3 um,scattering dir= .5  TOTAL RESPONSE =  2.184413
for size D= 4 um,scattering dir= .5  TOTAL RESPONSE =  1.03811
for size D= 5 um,scattering dir= .5  TOTAL RESPONSE =  .6076973
for size D= 6 um,scattering dir= .5  TOTAL RESPONSE =  .4185756
for size D= 8 um,scattering dir= .5  TOTAL RESPONSE =  .2432475
for size D= 10 um,scattering dir= .5  TOTAL RESPONSE =  .159714


for size D= .25 um,scattering dir= .7  TOTAL RESPONSE =  6.166012
for size D= .5 um,scattering dir= .7  TOTAL RESPONSE =  9.793645
for size D= .75 um,scattering dir= .7  TOTAL RESPONSE =  9.945831
for size D= 1 um,scattering dir= .7  TOTAL RESPONSE =  7.612793
for size D= 2 um,scattering dir= .7  TOTAL RESPONSE =  .974343
for size D= 3 um,scattering dir= .7  TOTAL RESPONSE =  .4703154
for size D= 4 um,scattering dir= .7  TOTAL RESPONSE =  .2810715
for size D= 5 um,scattering dir= .7  TOTAL RESPONSE =  .1678711
for size D= 6 um,scattering dir= .7  TOTAL RESPONSE =  .1220904
for size D= 8 um,scattering dir= .7  TOTAL RESPONSE =  6.807085E-02
for size D= 10 um,scattering dir= .7  TOTAL RESPONSE =  4.391967E-02


for size D= .25 um,scattering dir= 1.57  TOTAL RESPONSE =  5.596863
for size D= .5 um,scattering dir= 1.57  TOTAL RESPONSE =  6.444484
for size D= .75 um,scattering dir= 1.57  TOTAL RESPONSE =  3.306193
for size D= 1 um,scattering dir= 1.57  TOTAL RESPONSE =  .4978374
for size D= 2 um,scattering dir= 1.57  TOTAL RESPONSE =  9.299169E-02
for size D= 3 um,scattering dir= 1.57  TOTAL RESPONSE =  3.183984E-02
for size D= 4 um,scattering dir= 1.57  TOTAL RESPONSE =  1.829453E-02
for size D= 5 um,scattering dir= 1.57  TOTAL RESPONSE =  1.541773E-02
for size D= 6 um,scattering dir= 1.57  TOTAL RESPONSE =  1.478655E-02
for size D= 8 um,scattering dir= 1.57  TOTAL RESPONSE =  1.274994E-02
for size D= 10 um,scattering dir= 1.57  TOTAL RESPONSE =  9.004239E-03
```

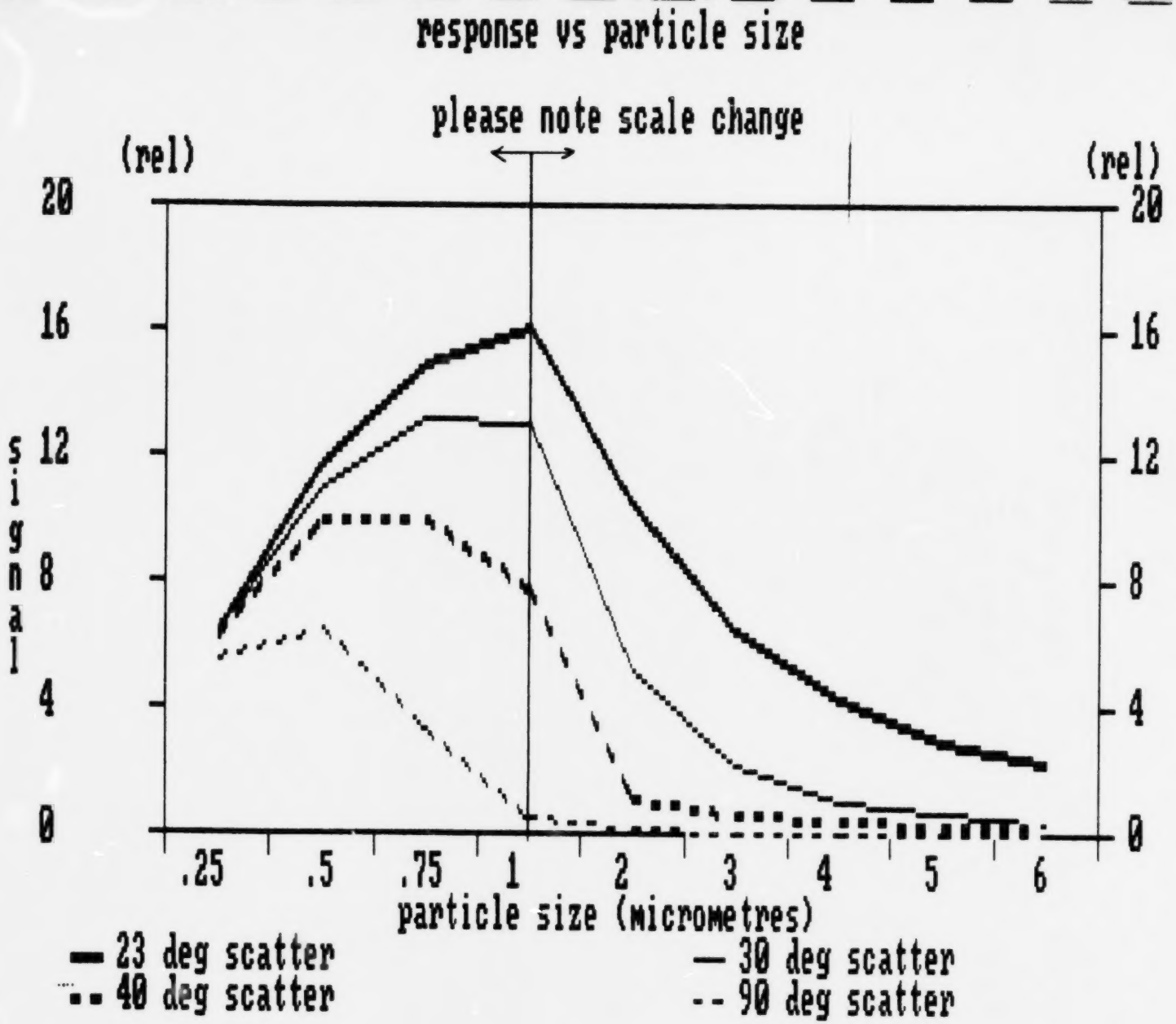

response vs particle size
please note scale change
(rel)
(rel)
20
16
12
8
4
0
signal
.25
.5
.75
1
2
3
4
5
6
particle size (micrometres)
23 deg scatter
30 deg scatter
40 deg scatter
90 deg scatter

Fig. 4

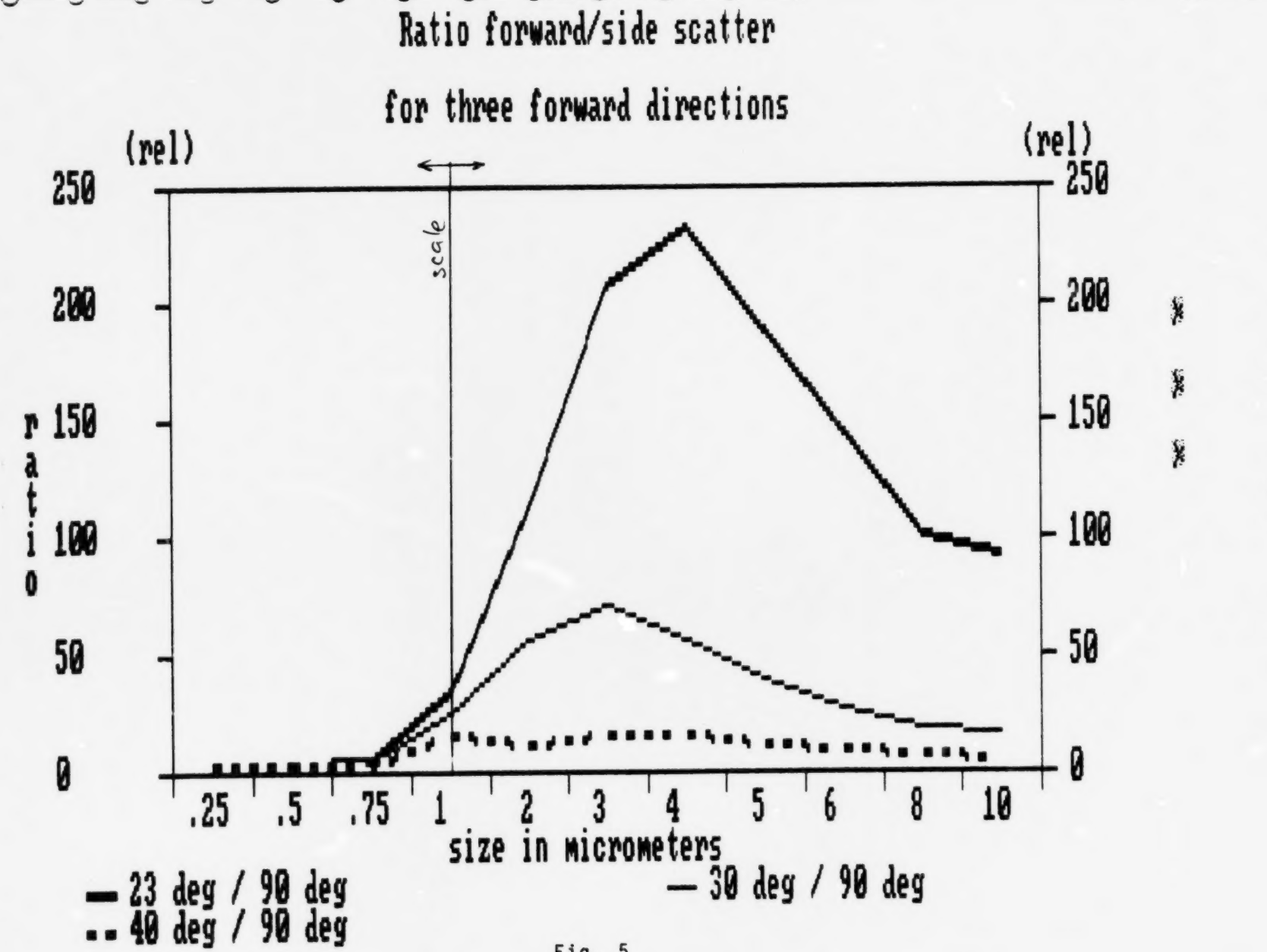

Ratio forward/side scatter
for three forward directions
(rel)
(rel)
250
200
150
100
50
0
ratio
scale
.25
.5
.75
1
2
3
4
5
6
8
10
size in micrometers
23 deg / 90 deg
40 deg / 90 deg
30 deg / 90 deg

Fig. 5

Page P4 is a printout of the total response (= detector light flux) for several particle diameters, for three selected forward scattering angles θ_o = 0.4, 0.5, 0.7 and for the side scatter θ_o = 1.57. These results are then graphed in subsequent figures.

Fig. 4 shows the detector signal, per unit volume of particulate matter, as a function of size. The 90^o geometry responds well to small particles and practically ignores the large ones. From the three forward scatter geometries the best is the 23^o (0.4 rad), since its response is the closest to the health hazard curve, peaking at about 1 μm and preserving the sensitivity up to 4 to 6 μm.

Fig. 5 shows the ratios of signals received by the forward and side channels. For example the ratio

$$R = \frac{\text{signal for } \theta_o = 0.4}{\text{signal for } \theta_o = 1.57}$$

is shown as 23 deg/90 deg scatter ratio.

It is clear that the 23^o forward scatter is superior to the others, less forward oriented alternatives. Here are some selected numbers:

Forward	0.25 μm	0.15	1	4	10 μm
23^o	1.1	1.8	32	231	92
30^o	1.1	1.7	26	57	16
40^o	1.1	1.5	15	15	4

The ratio, which is a measure of the distinguishing capability between diesel and mineral aerosols, decreases as the forward LED is put on a larger angle. At the time of writing, the forward LED is placed at about 40^{o}, to minimize the background that may result from LED light impinging on the mechanical sleeve of the detector lens. In light of the above results the detector lens holder will be rebuilt, to allow a better forward LED placement to a 30^{o} angle. Smaller angle can be achieved only by limiting the apertures of detector lens and the sample space.

For computations it is often necessary to assume a size distribution for the two types of particulates. The considered size distribution is usually lognormal (Mercer, 1973), described by the equation

$$f(d) = \frac{1}{(GSD)\cdot(2\pi)^{\frac{1}{2}}} \exp - \left[\frac{(\ln \frac{d}{MMD})^2}{2\ (GSD)^2} \right] \qquad (10)$$

where

f(d) - distribution of mass or volume

GSD - geometric standard deviation (dimensionless)

MMD - mass mean diameter (μm)

d - variable diameter (μm)

ln - natural logarithmus

Knight (1982) showed that the range of lognormal clouds in mine dust is described by

GSD of 2 to 3 (occasionally 4, if multicomponent dust is present).

MMD of 3 to 7 μm which corresponds to optical 2 to 5 with hard rock, and up to 10 with coal.

The diesel component is possibly multimodal and would be represented by an MMD of 0.1 to 0.5.

4. SIGNAL PROCESSING

The function of the system is based on the difference in light scattering pattern for large (mineral) and small (diesel) particles.

The system has two light-emitting diodes, one illuminating the suspended particles at an angle of 90^{o} to the axis of main detector, the other at an angle of 30^{o} (or other selected direction) to the main detector axis. Each of the LEDs has a reference detector placed opposite to it, to monitor its radiation intensity.

The LEDs are energized in sequence; the 90^{o} LED is energized first, giving detector signal X, the 30^{o} LED next, producing a signal Y.

The main detector signals X, Y are normalized by signals from the reference detectors, Rx, Ry.

The signals X, Y respond to both types of aerosol in the additive way:

$$\begin{aligned} X &= a\,D + b\,M \quad (\text{for } 90^{o}\text{ LED}) \\ Y &= c\,D + e\,M \quad (\text{for } 30^{o}\text{ LED}) \end{aligned} \tag{11}$$

where D = concentration of diesel fumes

M = concentration of mineral dust

a, b, c, e, = sensitivities

By solving Eq. 11 we obtain:

$$D = \frac{1}{a - c\,\frac{b}{e}} \left(X - \frac{b}{e}\,Y\right)$$

$$M = \frac{1}{b - e\,\frac{a}{c}} \left(X - \frac{a}{c}\,Y\right) \qquad (12)$$

The gains of the channels are defined as

$$G_D = \frac{1}{a - c\,\frac{b}{e}}$$

$$G_M = \frac{1}{b - e\,\frac{a}{c}} \qquad (13)$$

The "separating constants" are

$$E = \frac{b}{e}$$

$$F = \frac{a}{c} \qquad (14)$$

We also introduce the output offset Z_D, Z_M, to get

$$D = G_D\,(X - E \cdot Y - Z_D)$$

$$M = G_M\,(X - F \cdot Y - Z_M) \qquad (15)$$

The offsets compensate the "clean air value" X_o, Y_o of X, Y.

$$Z_D = X_o - E \cdot Y_o$$

$$Z_M = X_o - F \cdot Y_o \qquad (16)$$

The references are used to normalize the signals X, Y and remove the potential variations in radiation flux.

As a result the final equation solved in the computer is:

$$D = G_D \left(\frac{X}{R_x} - E \cdot \frac{Y}{R_y} - Z_D\right)$$

$$M = G_M \left(\frac{X}{R_x} - F \cdot \frac{Y}{R_y} - Z_M\right) \qquad (17)$$

The signals X (90^o LED) and Y (30^o LED) are supplied from the optical system, while the constants G_D, G_M, E, F, Z_D, Z_M, are read from a set of trimpots, adjustable in a range of 0 to 1 V.

Fig. 6 shows the response to diesel fumes and mineral dust, represented by Eq.17.

In the upper part of the figure is shown an approximate size distribution of both aerosols. Diesel has a prevailing particle size of 0.05 μm with chains and aglomerations forming larger

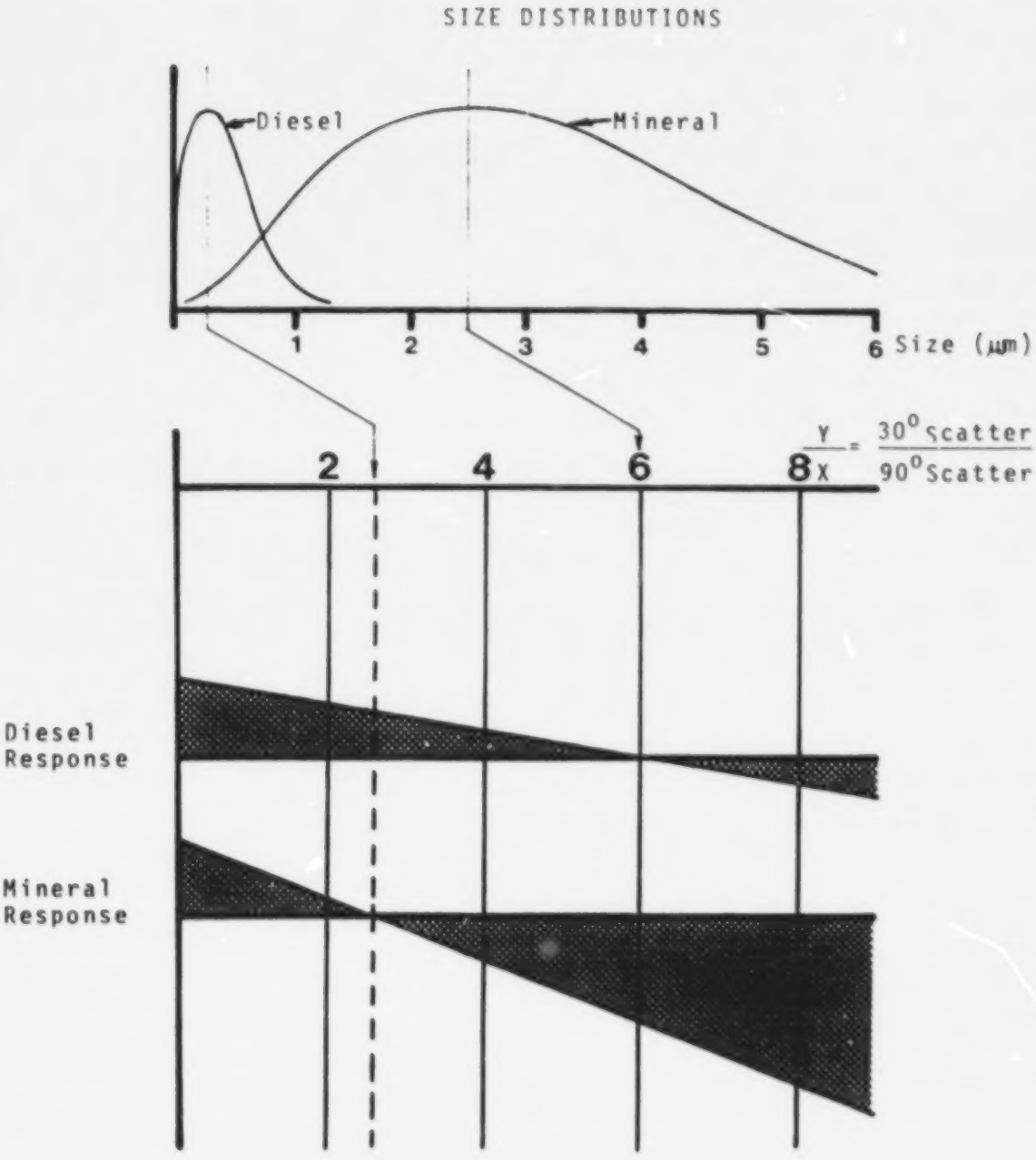

SIZE DISTRIBUTIONS
Diesel
Mineral
1
2
3
4
5
6
Size (μm)
2
4
6
8
X
Y = 30° Scatter / 90° Scatter
Diesel Response
Mineral Response

Fig. 6

particles up to 1 μm. Mineral dust is distributed in a wide range from 0.1 to 10 μm. The instrument is sensitive mainly to the respirable range of mineral dust between 0.5 and 5 μm, with a peak at about 1 μm. This sensitivity results from its geometry.

Each typical size distribution of particulates gives a different ratio of signals X/Y, as shown in Fig. 6, where also the equations (17) are expressed graphically as the diesel and mineral responses. It can seen that the diesel response is made not to respond to a "typical" mineral dust and vice versa.

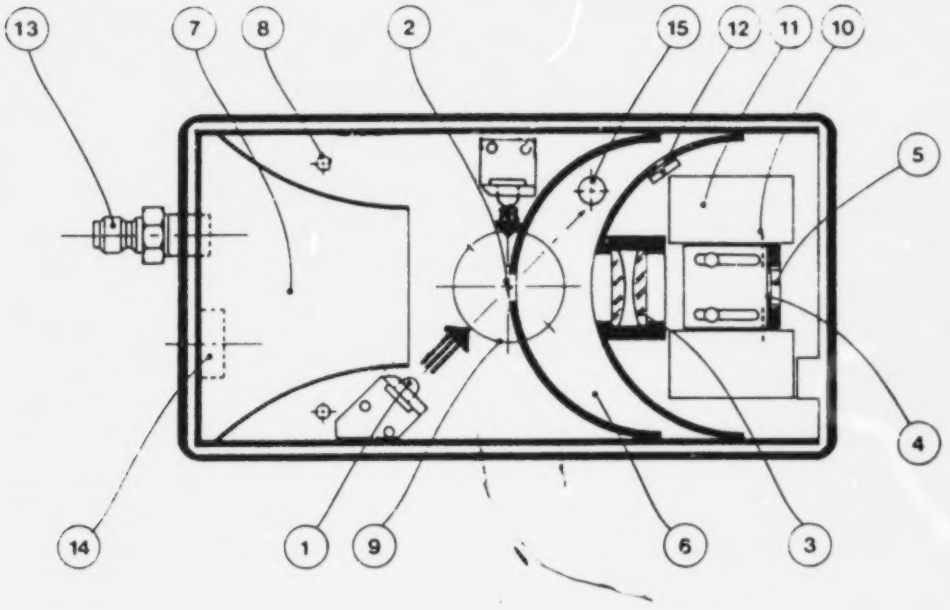
5. OPTICAL SYSTEM

The system is shown in Fig. 7. Two LEDs (1) illuminate the aerosol suspended in the vicinity of an opening (2) in the partition. The opening is projected by a lens (3) on a mask (4) placed directly in front of the detector (5). The mask cuts off the images of edges of the opening (2) to minimize the background signal caused by light diffraction and by whiskers or dust particles caught on the edges. Reference detectors (12) and (12a) are directly illuminated by the diodes.

A system of light traps is designed to minimize the background offset signal of the detector. The main light trap (7) provides a dark background for the illuminated particles, while the secondary traps (6) and (8) help to distroy redundant light emitted by the LEDs. The system can be operated without the main light trap with the left wall removed to prevent reflections of light from it. Since the tests in the mine showed a signal background changes due to dust deposits in the main light trap, the system will now be tested in an open configuration.

The air enters the sample space by natural drafts and diffusion through the windows (9).

Calibration of zero line will be accomplished by periodic filling of the instrument with clean filtered air. Also, the instrument can be occasionally cleaned after the removal of lid (17) and casing (16).



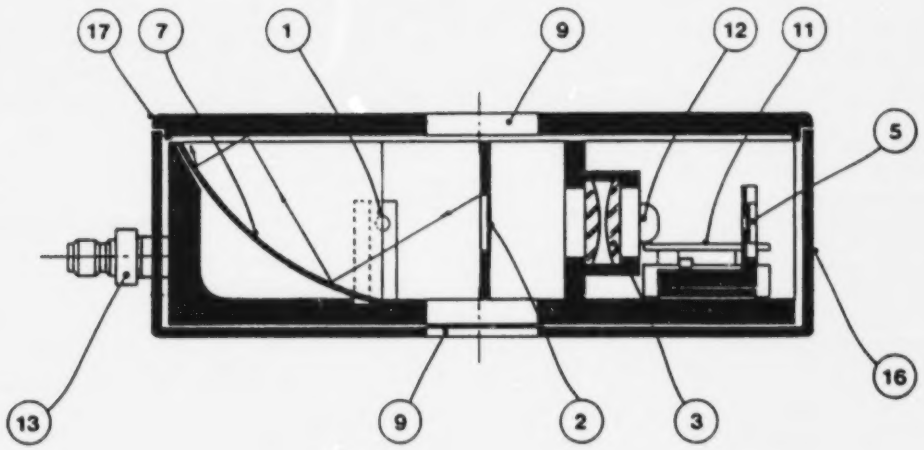
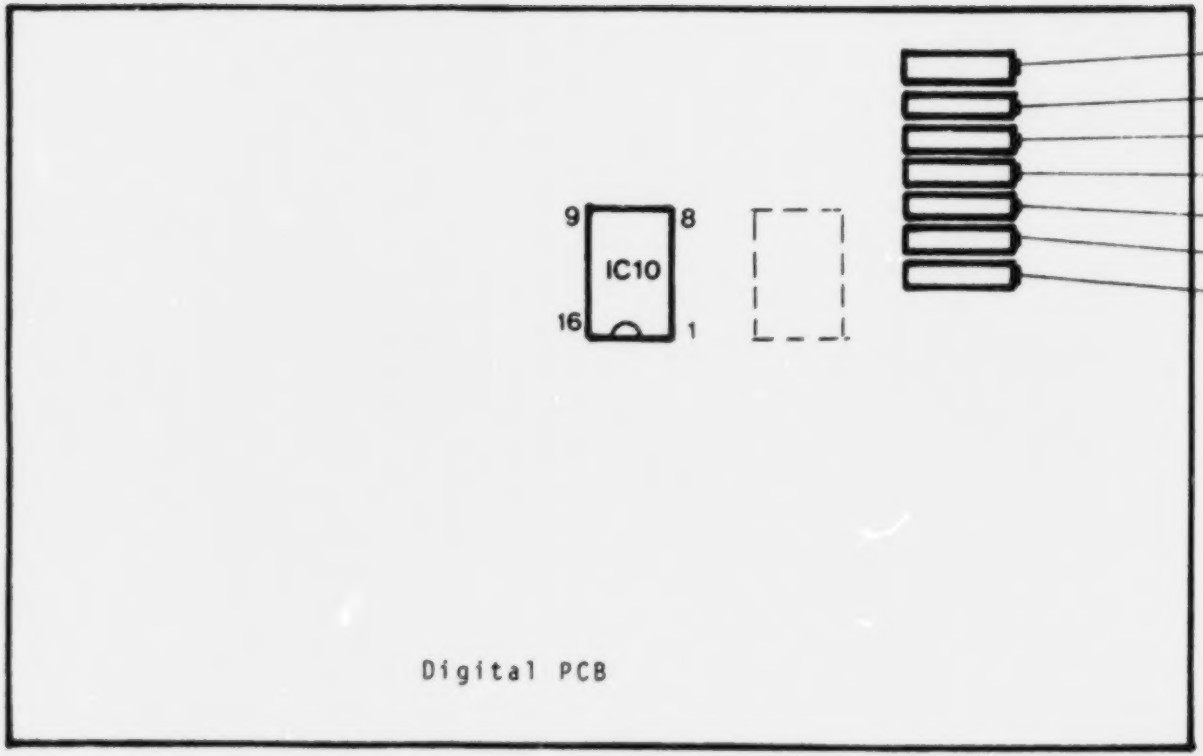


Fig. 7

Sensing Head
Diesel/Mineral Monitor



Pin 13	Ch.D	E
Pin 15	Ch.D	SCALE
Pin 12	Ch.M	F
Pin 1	Ch.M	OFFSET
Pin 5	Ch.M	SCALE
Pin 2	NOT USED	
Pin 14	Ch.D	OFFSET

NOTE: All Pin #'s refer to IC10

Ch.M=Mineral
Ch.D=Diesel

TRIMPOT REFERENCES

Fig. 8

6. ADJUSTMENT PROCEDURE

The voltages representing the constants expressed by Eq. (13) and (14) are entered through a set of trimpots on the upper (computer) PC board. Fig. 8 shows the location and functions of the chip pins where the trimpot voltages can be monitores with a DC voltmeter.

The upper board has also pins allowing to view the main and reference signals on the scope. The signals (in sequence X, Y) appear intermittently every 1 sec, as shown in Fig. 9.

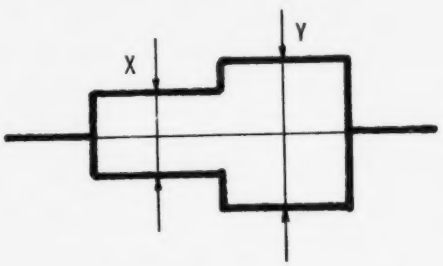


Fig. 9

Each channel (diesel and mineral) has three adjustments:

zero offset

scale (gain)

constant E or F

To identify the mineral channel we use the fact that it has a negative output (the computer alghoritm reverses the sign of the mineral output). When we set the constants E and F to zero, so that only the X signal is sensed, we get from Eq. (17)

$$D = G_D \cdot X$$

$$M = -G_M \cdot X$$

The channel giving a negative output with smoke in the sample chamber is thus identified as mineral.

Setting the separation constants requires either a real smoke in the sample chamber or a thin nylon fibre hanging through the sample space with its lower end attached to a small weight submerged in water, to damp the fibre motion. The fibre is moved into a position which gives a required ratio of signals X/Y, with absolute value of these signals not exceeding about 150 mV (300 mV peak-to-peak) to avoid saturation.

By a measurement of signals X, Y on the scope with actual diesel fumes and mineral dust in the sample chamber, the ratios of the forward and side scatter signals can be established and averaged on a large number of measurements. A fibre can now be manipulated into a position in the sample space where it gives the ratios previously obtained by diesel or mineral dust.

The constants E and F are now adjusted to get mineral reading equal to zero when diesel signal is generated and vice versa. If a "standard" diesel and mineral are available, then no fibre is needed and we adjust E and F by adjusting diesel output to zero with mineral in the chamber and mineral output to zero with diesel fumes in the chamber.

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TECHNICAL APPENDIX

Electrical Schematics

The electrical schematics shows the division between the analog and computer PC board by a dashed line.

The analog system utilizes new programmable low-power CMOS operational amplifier TLC271, Texas Instruments. They require only a single power supply 5V. They are switched on by the computer only for 1 sec, subsequently they "hibernate" with a very low power consumption.

Components CD4053 and CD4051 are used for the synchronous detection.

The computer reads the two analog signals together with trimpot settings through a multiplexer (CD4051 on the right of the page). The microprocessor IC6 utilizes the program stored in the EPROM (IC1).

The component placement schematics corresponds to the electrical schematics (e.g. the socket mounted exchangeable EPROM is shown as IC1 on both schematics).

Printer prints one day (on PRINT command) or 7 days (on PRINT ALL). The page format is enclosed. One column represents one hour with 12 readings, 4 minutes appart. Each reading is an average of 5 subsequent 1 minute readings. There are two three-digit numbers side by side - first is the diesel reading, second is the mineral. Decimal points are left out. It is possible to program them in if a compressed printing form is used.

Switch setting for Mannesmann Spirit Printer

Sw1:	1	2	3	4	5	6	7	8
	1	0	1	0	0	0	1	0

Sw2:	1	2	3	4
	1	1	0	1

Control box

Without the control box the monitor is energized once every minute in the operational mode. Data are displayed and stored.

The control box allows to put the monitor into a test mode: reading is taken every second, no storage is done.

The control box also allows to print out the store content. For that it must be plugged into 110 V and the printer must be on. The PRINT command, followed by EXECUTE prints 1 day, PRINT ALL - EXECUTE prints 7 days.

Power

The C-size rechargeable batteries give a week of service in the operational 1 minute mode. The monitor can also be operated with the charger permanently attached.

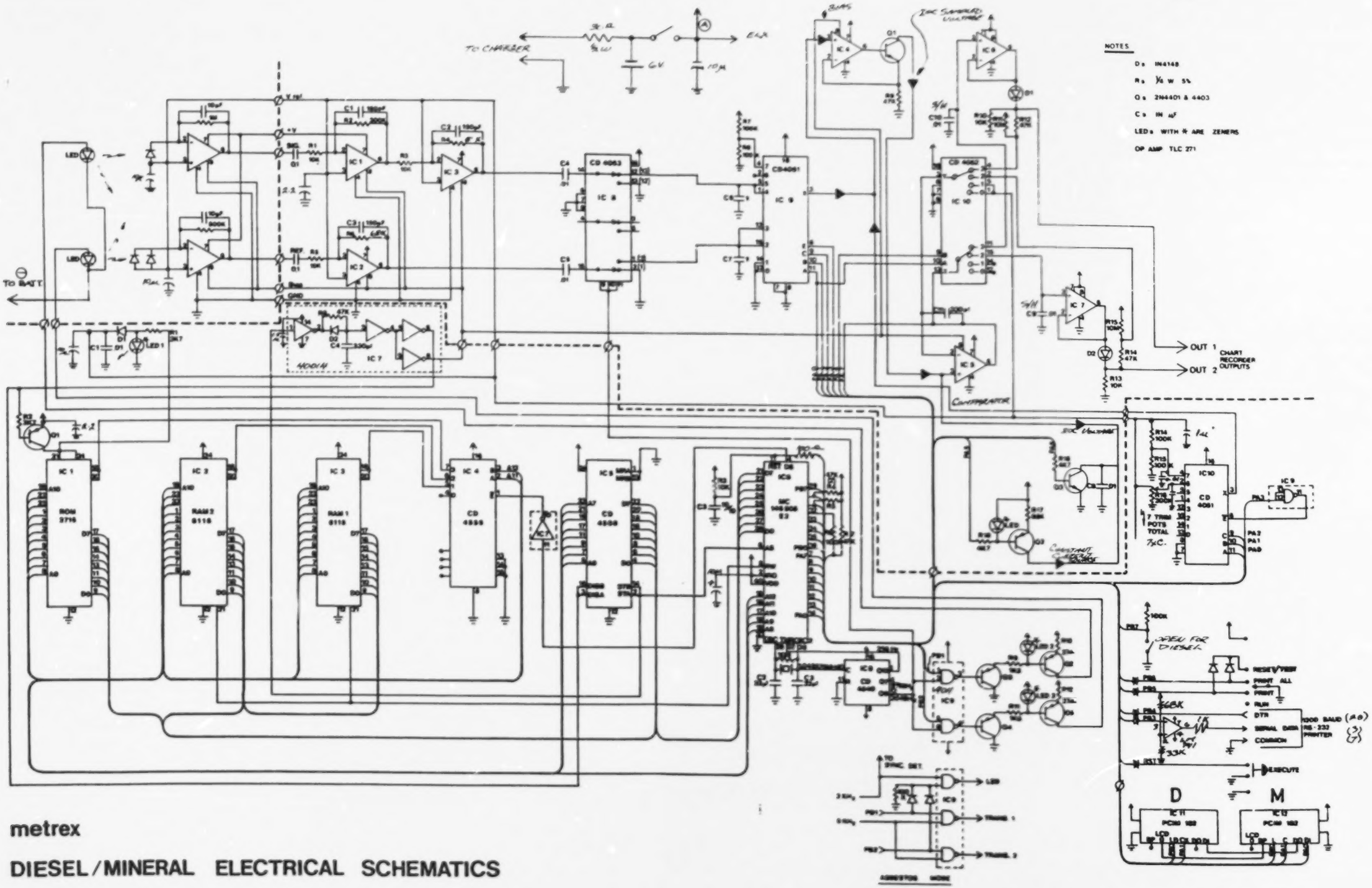
Example of trimpot setting - Unit No. 002

Gain Diesel 1 V

Gain Mineral 1 V

Constant E = 0.033 V

Constant F = 0.043 V



NOTES

D = IN4148

R = ¼ W 5%

Q = 2N4401 & 4403

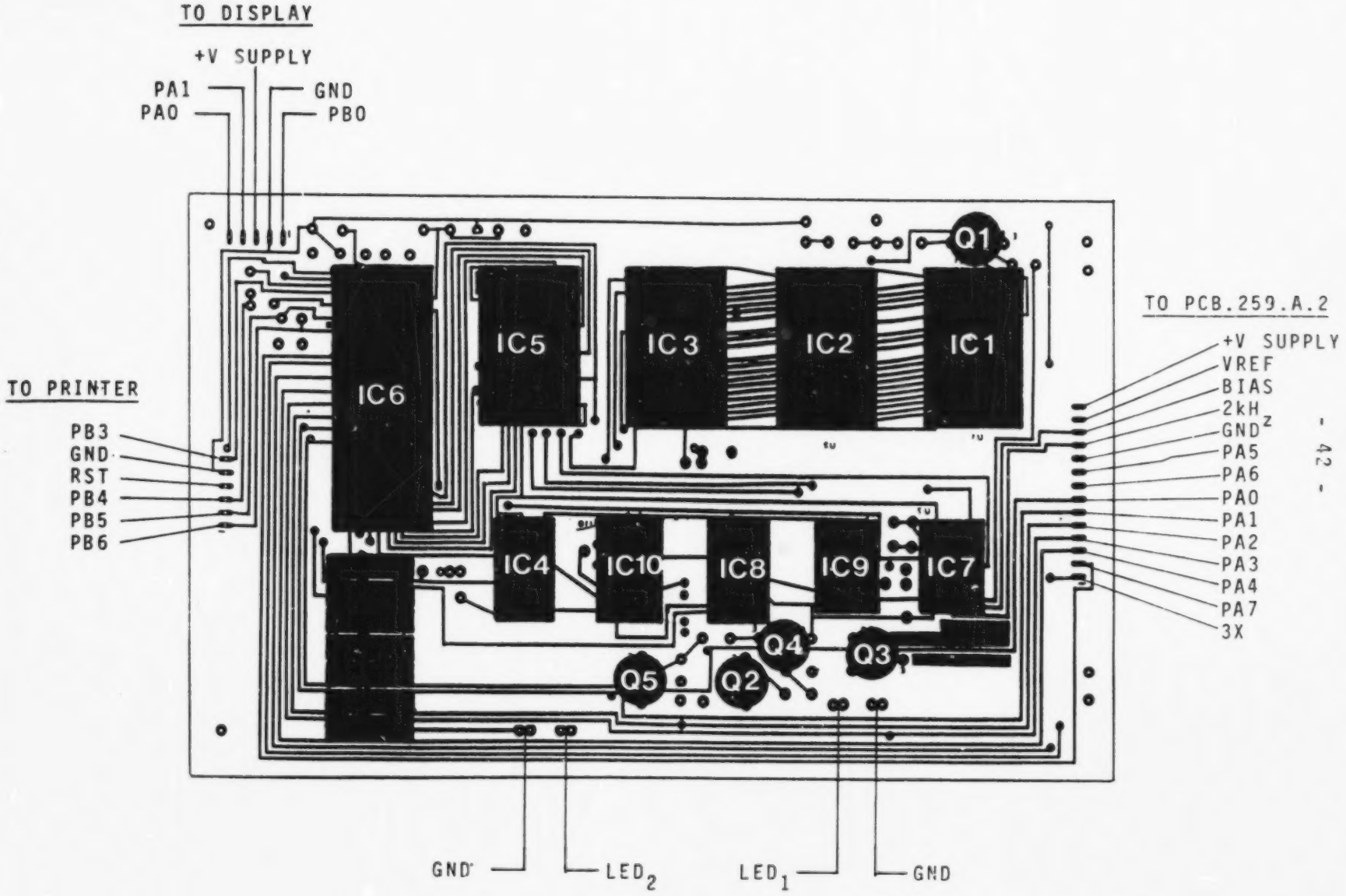
C = IN µF

LED = WITH * ARE ZENERS

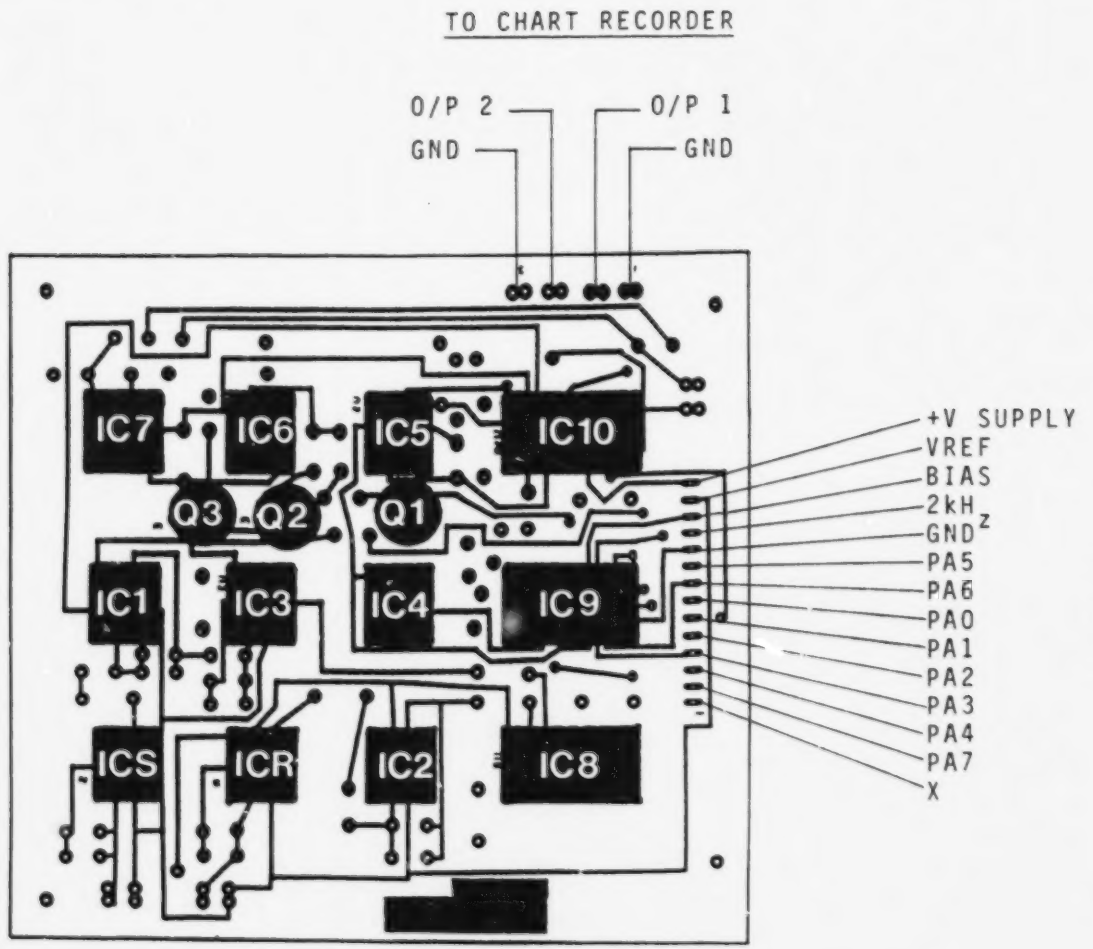
OP AMP TLC 271

metrex

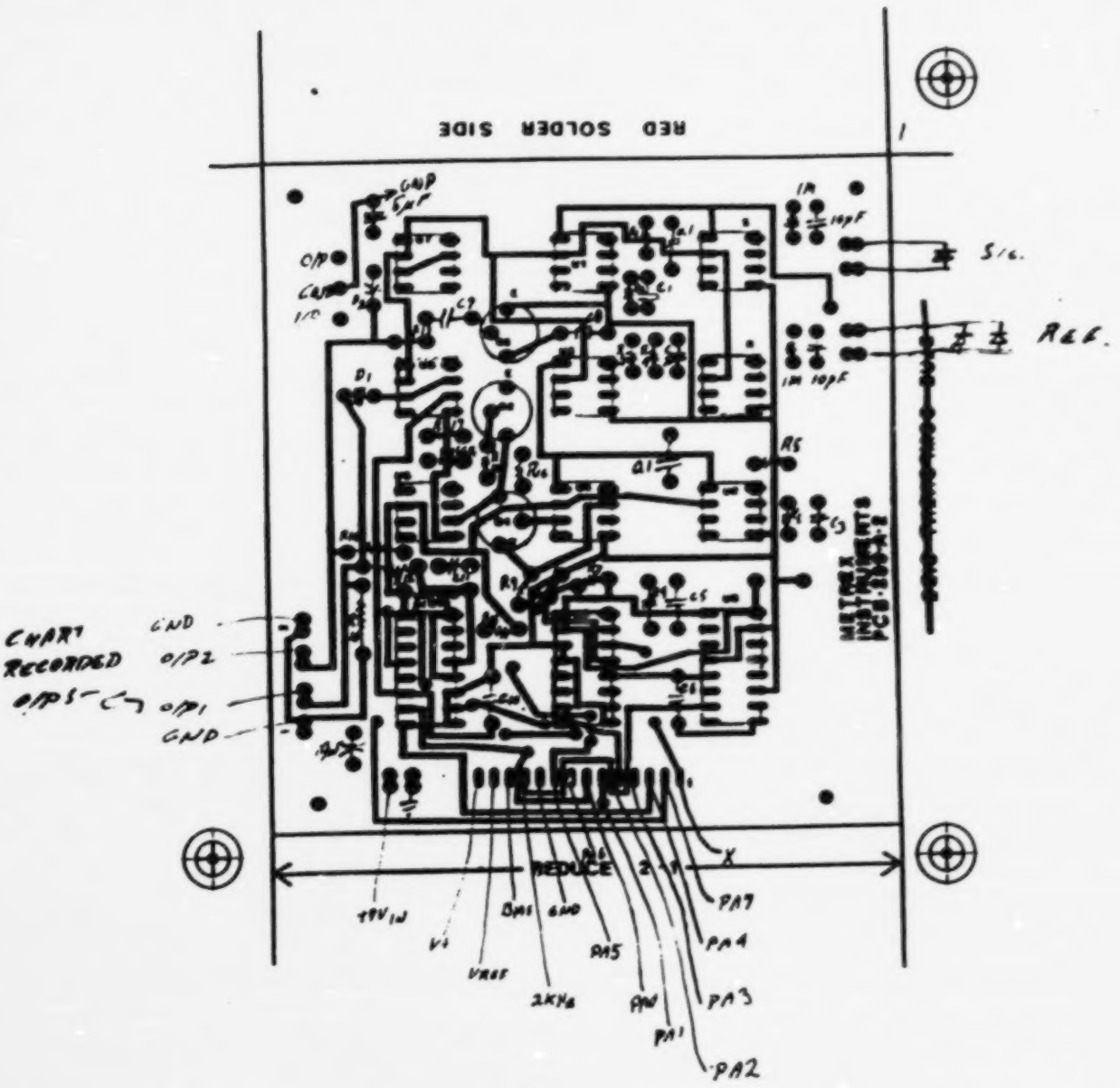
DIESEL / MINERAL ELECTRICAL SCHEMATICS



DIESEL/MINERAL - DIGITAL BOARD (COMPONET SIDE)



DIESEL/MINERAL - ANALOGUE BOARD (COMPONENT SIDE)


RED SOLDER SIDE
REDUCE
CHART RECORDER O/PS
GND
O/P2
O/P1
GND
S/c.
R&C.
X
PA7
PA6
PA5
PA4
PA3
PA2
PA1
PA0
2KHz
VREF
GND

MAY [illegible]

BASE COMPONENT SIDE

GND LED1 LED2 GND

P1 ↑ P3

PRINTER CONNECTION

PB3 GND RST PB4 PB5 PB6

DISPLAY CONNECTIONS

PB0 GND +5 PA1 PA0

REDUCE TO 2·1

CONNECTIONS TO PCB·259·A·2

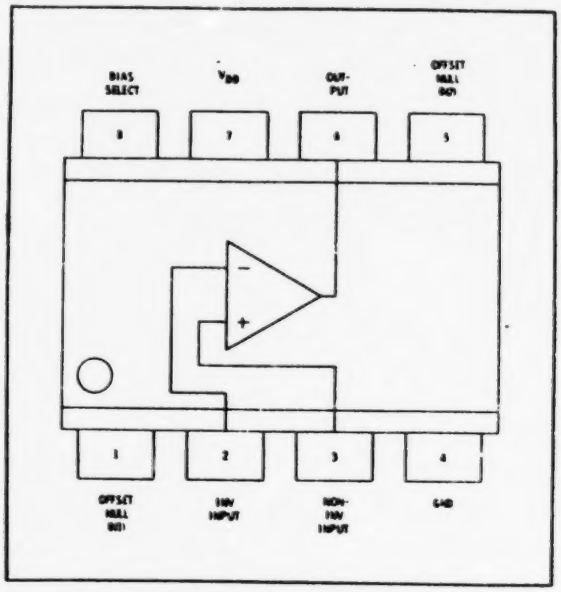
3X
PA7
PA1
PA3
PA2
PA1
PA0
PA6
PA5
CAP6
2K#y
BAS
VREF
+VSUPPLY

TYPES TLC251 and TLC271
PROGRAMMABLE LOW-POWER
LinCMOS™ OPERATIONAL AMPLIFIERS

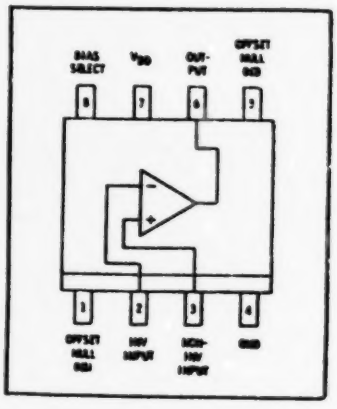
features

- Wide Range of Supply Voltages:
  1 V to 16 V (TLC251)
  4 V to 16 V (TLC271)
- True Single Supply Operation ...
  The Common-Mode Input Voltage Range Includes the Negative Rail.
- Low Supply Current is Programmable...
  Low = 10 uA typical
  Medium = 150 uA typical
  High = 1000 uA typical
- Extremely Low Input Bias and Offset Currents:
  Input Bias Current... 1 pA typical
  Input Offset Current... 1 pA typical
- Low Input Offset Voltage...
  2 mV Max
- Ultra stable Input Offset Voltage...
  0.1 uV/mo. typical
  0.7 uV/°C typical at low bias
- Low Noise... 30 nV/√Hz typical
- High Slew Rate:
  High Bias... 4.5 V/us typical
  Medium Bias... 0.6 V/us typical
  Low Bias... 0.04 V/us typical

P DUAL-IN-LINE PACKAGE (TOP VIEW)



D SMALL OUTLINE PACKAGE (TOP VIEW)



description

The TLC251 and TLC271 are low cost, low power, programmable operational amplifiers designed to operate with single or dual supplies. Unlike traditional metal gate CMOS op amps, these devices utilize Texas Instruments' silicon gate LinCMOS™ process, giving them stable input offset voltages without sacrificing the advantages of metal gate CMOS. This series of parts is available in selected grades of input offset and can be nulled with one external potentiometer. Because the typical input common-mode range extends to the negative rail, and the power consumption is extremely low, this family is ideally suited for battery powered or energy conserving applications. A bias select pin can be used to program one of three AC performance and power dissipation levels, from a high level (slew rate of 4.5 V/us, power dissipation of 10 mW at a supply voltage of 10V volts) to a low level (slew rate of 0.04 V/us, consuming only 100 uW at 10 volts) to suit the application. The TLC251 offers the same operation as the TLC271, but also features guaranteed operation down to a 1 volt supply. Both devices are unity gain stable and have excellent noise characteristics.

Because of the extremely high input impedance and low input bias and offset currents, applications for the TLC251 and TLC271 series include many areas that have previously been limited to BIFET and NFET product types. Any circuit using high impedance elements and requiring small offset errors is a good candidate for cost effective use of these devices. Many features associated with bipolar technology are available with LinCMOS operational amplifiers without the power penalties of traditional bipolar devices. General applications such as transducer interfacing, analog calculations, amplifier blocks, active filters and signal buffering are all easily designed with the TLC271. Remote and inaccessable equipment applications are possible using the low voltage and low power capabilities of the TLC251. In addition, by driving the bias select input with a logic signal from a microprocessor, these operational amplifiers can have software-controlled performance and power consumption. The TLC251 is well suited to solve the difficult problems associated with single battery and solar cell powered applications. These devices are characterized for operation over 0 to 70°C and are available in both 8-pin plastic dual-in-line (DIP) and small outline (SO) packages.

ADVANCE INFORMATION

This document contains information on a new product. Specifications are subject

MC 146805 MICROPROCESSOR

ASSEMBLY PROGRAM LISTING

```
   1                000A  LF       EQU    $0A
   2                000C  FF       EQU    $0C
   3                000D  CR       EQU    $0D
   4
   5                      * IO LOCNS
   7                      * CSC 6805 MACRO SET V1.0
   8                             OPT    NOE,NOM
 508                      * ************************************
 509                             OPT    MAC
 510                             OPT    PAG
 511                0000  PZBASE   EQU    $0
 512                0000  EXPIO    EQU    $0000
 513                0000  PORTA    EQU    EXPIO
 514                0001  PORTB    EQU    EXPIO+1
 515                0004  PORTDA   EQU    PORTA+4
 516                0005  PORTDB   EQU    PORTB+4
 517                0008  TMRD     EQU    8
 518                0009  TMRC     EQU    9
 519
 520                0000  RAM      EQU    PZBASE*256
 521                0018  RAMEND   EQU    PZBASE+24 ***
 522                0008  RAMSTH   EQU    PZBASE+8
 523                0002  RAMSTL   EQU    2
 524                000F  RAMSZH   EQU    RAMEND-RAMSTH-1
 525                00FE  RAMSZL   EQU    256-RAMSTL
 526
 527  0010                       ORG    RAM+$10
 528
 529                      * MODIFYABLE CODE POKED HERE !
 530                      * THIS ORDER MUST STAY
 531
 532  0010                GETRTN   RMB    1
 533  0011                GETPTR   RMB    3          CURRENT READ LOC'N
 534  0014                SAVRTN   RMB    1
 535  0015                SAVPTR   RMB    3          POINTER FOR WRITE
 536  0018                PWRCHK   RMB    4
 537
 538  001C                TMPHI    RMB    1
 539  001D                TMPLO    RMB    1
 540  001E                XT1      RMB    2
 541  0020                XT2      RMB    2
 542  0022                TMP1     RMB    1
 543  0023                HTMP     RMB    1
 544  0024                MDCTR    RMB    1
 545  0025                M1DSH    RMB    1          M1/DIVISOR
 546  0026                M1DSL    RMB    1
 547  0027                M2DQH    RMB    1          M1/QUOTIENT
 548  0028                M2DQL    RMB    1
 549  0029                MPDDH    RMB    1          PRODUCT/DIVIDEND
 550  002A                MPDD2H   RMB    1
 551  002B                MPDD2L   RMB    1
 552  002C                MPDDL    RMB    1
 553  002D                MOD5     RMB    1          5 MINUTE CTR
 554
 555  002E                DATAST   RMB    2          START OF DATA FOR READ
 556
 557                      * USED BY PRNT RTN ONLY; RECYCLED FOR OCTMP
```

```
558
559  0030                COLNUM  RMB    1          PRINTHEAD POSN 0-79
560  0031                DAYNUM  RMB    1
561  0032                MOD3    RMB    1
562  0033                MOD4    RMB    1
563  0034                DATAC   RMB    1          DATA PER LINE
564  0035                PRNDAT  RMB    2          OUTPUT SHIFT REG
565  0037                GBASEH  RMB    1          GET RTN BASE ADDR
566  0038                GBASEL  RMB    1
567  0039                PDCTRH  RMB    1          PRINT DATA TO GO CTR
568  003A                PDCTRL  RMB    1
569  003B                PRHRCT  RMB    1          HOUR COUNT
570
571  0030                        ORG    COLNUM
572
573  0030                OCTMP   RMB    8
574  0038                ADCH    RMB    1
575  0039                ADCL    RMB    1
576  003A                DACH    RMB    1
577  003B                DACL    RMB    1
578  003C                DATAXH  RMB    1          INTERMEDIATE DATA
579  003D                DATAXL  RMB    1
580  003E                DATAYH  RMB    1
581  003F                DATAYL  RMB    1
582  0040                OUTDAT  RMB    4
583  0044                AVGDAT  RMB    4
584
585  0048                CONMEM  RMB    16         MEM FOR CONST'S
586  0058                ASCBUF  RMB    7
587
588            1800  ROM       EQU    3*2048
589  1800                      ORG    ROM
590  1800 00                   FCB    0          DUMMY TO FOOL LOADER
591
592  1FF6                      ORG    ROM+$7F6
593
594  1FF6 1C0B                 FDB    TMRIRQ     TMR-WAIT
595  1FF8 1C0B                 FDB    TMRIRQ     TMR-RUN
596  1FFA 1C0B                 FDB    TMRIRQ     EXT IRQ
597  1FFC 1870                 FDB    COLDB      SWI
598  1FFE 1870                 FDB    COLDB      COLD BOOT
599
600  1800                      ORG    ROM
601
602                     * SOURCE FOR MODIFYABLE CODE TO SUPPORT
603                     * 4K OF RAM. 12 BYTES MUST STAY IN ORDER
604
605  1800               MODCOD
     1800                      LDA    $FFFF
     1803                      RTS
     1804                      STA    $FFFF
     1807                      RTS
610  1808               PURDAT
611  1808 1234                 FDB    $1234      ASSUME RAM WON'T CONTAIN
```

```
612  180A 4321                FDB    $4321     THIS AT PWRUP
613
614                    * 7 SEG TABLE
615
616  180C              SEG7
617  180C 7E                  FCB    $7E       0
618  180D 18                  FCB    $18       1
619  180E B6                  FCB    $B6       2
620  180F BC                  FCB    $BC       3
621  1810 D8                  FCB    $D8       4
622  1811 EC                  FCB    $EC       5
623  1812 EE                  FCB    $EE       6
624  1813 38                  FCB    $38       7
625  1814 FE                  FCB    $FE       8
626  1815 F8                  FCB    $F8       9
627
628                    * DIGIT TABLE
629
630  1816              BCDTBL
631  1816 2710                FDB    10000
632  1818 03E8                FDB    1000
633  181A 0064                FDB    100
634  181C 000A                FDB    10
635  181E 0001                FDB    1
636
637  1820              MSGS
638  1820 4D 49 4E 45  M1       FCC    "MINERAL-",4
639  1829 44 49 45 53  M2       FCC    "DIESEL",4
640  1830 41 53 42 45  M3       FCC    "ASBESTOS",4
641  1839 20 44 55 53  M4       FCC    " DUST MONITOR REPORT",4
642  184E 50 41 47 45  M5       FCC    "PAGE ",4
643  1854 44 2E 48 48  M6       FCC    "D.HH.MM",4
644  185C 20 20 20 30  M7       FCC    "   0.",4
645  1862 2E 30 30 04  M8       FCC    ".00",4
646  1866 2D 2D 2D 20  M9       FCC    "--- ---",4
647
648                    *+ MON:
649                    * PUTS 1ST  64 BYTES REL "Y" ON SCREEN
650                    * AT $E400
651
652  186E              MON
     186E                       RTS
654
655  186F              ENDCHK
     186F                       RTS
657
658                    *+ COLDB: COLD BOOT POINT
659
660  1870              COLDB
     1870                       RSP    RST       STACK PTR
     1871                       LDAI   (%67)     %01100111
     1873                       STAZ   TMRC      DISABLE TMR IRQ'S
     1875                       LDAI   ($7F)     7 OUT AT A
     1877                       STAZ   PORTDA
```

```
        1879                        LDAI   ($0F)      4 OUT AT B
        187B                        STAZ   PORTDB
        187D                        LDXI   (4)        CHECK 4 BYTES OF RAM
669     187F                BK79
        187F                        LDA    PWRDAT-1,X
        1882                        CMPA   PWRCHK-1,X AGAINST ROM
672     1885 26   06                BNE    FD46       BR IF PWR WAS OFF
        1887                        DEX
674     1888 26   F5                BNE    BK79
        188A                        JMP    WASPWR     HERE IF PWR WAS ON
676     188D                FD46
        188D                        LDXI   (12)       COPY MODIFYABLE CODE
678     188F                BK82
        188F                        LDA    MODCOD-1,X AND PWR CHK DATA
        1892                        STA    GETRTN-1,X
        1895                        DEX
682     1896 26   F7                BNE    BK82
        1898                        LDAI   (RAMSTH)   INIT DATA POINTERS
        189A                        STAZ   SAVPTR
        189C                        STAZ   DATAST
        189E                        LDAI   (RAMSTL)
        18A0                        STAZ   SAVPTR+1
        18A2                        STAZ   DATAST+1
689     18A4                BK71
        18A4                        LDAI   ($FF)      FILL DATA WITH FF'S
        18A6                        JSR    SAVRTN
        18A9                        JSR    SAVINC
        18AC                        LDAZ   SAVPTR+1
        18AE                        CMPAI  (RAMSTL)
695     18B0 26   F2                BNE    BK71
        18B2                        LDAZ   SAVPTR
        18B4                        CMPAI  (RAMSTH)
698     18B6 26   EC                BNE    BK71
699     18B8                WASPWR
        18B8                        LDAZ   PORTB      CHK TEST SW
        18BA                        ANDAI  ($60)
702     18BC 27   2F                BEQ    TEST       BR IF TEST ON
        18BE                        CMPAI  ($40)
704     18C0 26   03                BNE    FD32
        18C2                        JMP    PRALL
706     18C5                FD32
        18C5                        CMPAI  ($20)
708     18C7 26   03                BNE    FD33
        18C9                        JMP    PRNT
710     18CC                FD33
        18CC                        LDAI   (5)        INIT 5 MIN TMR
        18CE                        STAZ   MOD5
        18D0                        LDXI   (4)        CLR 4 BYTES AVGDAT
714     18D2                BK68
        18D2                        CLR    AVGDAT-1,X
        18D4                        DEX
717     18D5 26   F8                BNE    BK68
        18D7                        JSR    CONINP     GET CONSTANTS
719     18DA                RUN
```

```
                18DA                        LDAI  ($37)     %00110111 CLR PENDING IRQ'S
                18DC                        STAZ  TMRC      AND ENABLE MORE
    722         18DE            RUNLOP
                18DE                        LDAI  (120)     60 SEC TIMEOUT
                18E0                        STAZ  TMRD
                18E2                        JSR   MESURE    MEASURE & DSPLY DATA
                18E5                        JSR   AVGCLC
                18E8                        JSR   WSUB
    728         18EB 20   F1                BRA   RUNLOP
    729         18ED            TEST
                18ED                        LDAI  ($67)     %01100111
                18EF                        STAZ  TMRC      DISABLE TMR IRQ'S
                18F1                        LDAZ  SAVPTR    UPDATE DATA START PTR
                18F3                        STAZ  DATAST
                18F5                        LDAZ  SAVPTR+1
                18F7                        STAZ  DATAST+1
    736         18F9            TSTLOP
                18F9                        JSR   CONINP    GET CONSTANTS
                18FC                        JSR   MESURE    MEASURE & DSPLY DATA
                18FF                        LDAZ  PORTB     CHK TEST SW
                1901                        ANDAI ($60)
    741         1903 27   F4                BEQ   TSTLOP    BR IF TEST ON
    742         1905 20   D3                BRA   RUN       RTRN TO RUNNING
    743
    744         1907            AVGCLC
                1907                        LDXI  (4)       ADD CUR DATA TO AVGDAT
    746         1909            BK85
                1909                        LDA   OUTDAT-1,X
                190C                        ADDA  AVGDAT-1,X
                190F                        STA   AVGDAT-1,X
                1912                        LDA   OUTDAT-2,X
                1915                        ADCA  AVGDAT-2,X
                1918                        STA   AVGDAT-2,X
                191B                        DEX
                191C                        DEX
    755         191D 26   EA                BNE   BK85      TWICE
                191F                        DECZ  MOD5      5 MIN UP ?
    757         1921 27   01                BEQ   FD29      BR IF YES
                1923                        RTS   DONE      !
    759         1924            FD29
                1924                        LDAI  (5)       RE-INIT TMR
                1926                        STAZ  MOD5
                1928                        LDXI  (4)
    763         192A            BK72
                192A                        LDA   AVGDAT-1,X MOVE DATA TO DIVISOR
                192D                        CLR   AVGDAT-1,X AND CLR AVGDAT
                192F                        STAZ  MPDDL
                1931                        LDA   AVGDAT-2,X
                1934                        CLR   AVGDAT-2,X
                1936                        STAZ  MPDD2L
                1938                        CLRZ  MPDD2H
                193A                        CLRZ  MPDDH
                193C                        LDAI  (5)       DIVIDEND= 5
                193E                        STAZ  M1DSL
```

```
                1940                        CLRZ    M1DSH
                1942                        JSR     DIVIDE
                1945                        LDAZ    M2DQL       SAVE THE QUOTIENT
                1947                        TSTZ    M2DQH       LIMIT TO 0 - 254
    778         1949 27   07                BEQ     FD48        BR IF OK
    779         194B 2B   04                BMI     FD34        BR IF NEG
                194D                        LDAI    ($FE)       TOO HI: CLIP AT 254
    781         194F 20   06                BRA     FD47
    782         1951                FD34
                1951                        CLRA    NEGATIVE, MAKE IT 0
    784         1952                FD48
                1952                        CMPAI   ($FF)       DON'T SAVE FF'S
    786         1954 26   01                BNE     FD47
                1956                        DECA
    788         1957                FD47
                1957                        JSR     SAVRTN      THE MODIFYABLE CODE !
                195A                        JSR     SAVINC
                195D                        JSR     SPTINC
                1960                        DEX
                1961                        DEX
    794         1962 26   C6                BNE     BK72        DO THE ABOVE TWICE
                1964                        RTS
    796
    797         1965                SAVINC
                1965                        LDAZ    SAVPTR+1    BUMP POINTER
                1967                        ADDAI   (1)
                1969                        STAZ    SAVPTR+1
                196B                        LDAZ    SAVPTR
                196D                        ADCAI   (0)
                196F                        CMPAI   (RAMEND)    CHK FOR END OF RAM
    804         1971 26   06                BNE     FD31        BR IF NOT
                1973                        LDAI    (RAMSTL)    RE-INIT TO STRT
                1975                        STAZ    SAVPTR+1
                1977                        LDAI    (RAMSTH)
    808         1979                FD31
                1979                        STAZ    SAVPTR
                197B                        RTS
    811
    812         197C                SPTINC
                197C                        LDAZ    SAVPTR
                197E                        CMPAZ   DATAST      COLLIDE W DATA START ?
    815         1980 26   1A                BNE     FD49
                1982                        LDAZ    SAVPTR+1
                1984                        CMPAZ   DATAST+1
    818         1986 26   14                BNE     FD49
                1988                        ADDAI   (2)         YES: ADJ DATA START
                198A                        STAZ    DATAST+1
                198C                        LDAZ    DATAST
                198E                        ADCAI   (0)
                1990                        CMPAI   (RAMEND)    CHK FOR WRAPAROUND
    824         1992 26   06                BNE     FD50
                1994                        LDAI    (RAMSTL)    YES: FIX IT
                1996                        STAZ    DATAST+1
                1998                        LDAI    (RAMSTH)
```

```
828  199A                FD50
     199A                        STAZ   DATAST
830  199C                FD49
     199C                        RTS
832
833  199D                OUTCHR
     199D                        STXZ   XT1
     199F                        ASLA
     19A0                        STAZ   PRNDAT+1  LSB= LO STRT BIT
     19A2                        LDAI   ($FF)     2 STOP BITS
     19A4                        STAZ   PRNDAT
     19A6                        LDXI   (10)      1+ 7+ 3
840  19A8                BK77
     19A8                        LDAZ   PORTB     PRNTR RDY ?
     19AA                        ANDAI  ($10)
843  19AC 27  FA                 BEQ    BK77      BR IF NOT
844  19AE                BK66
     19AE                        LDAZ   PORTB     3,5
     19B0                        LSRZ   PRNDAT    HI 5,6
     19B2                        RORZ   PRNDAT+1  LO 5,6
848  19B4 25  04                 BCS    FD52      3,3
     19B6                        ORAI   ($8)      2,2
850  19B8 20  04                 BRA    FD53      3,3
851  19BA                FD52
     19BA                        ANDAI  ($F7)     2,2
853  19BC 20  00                 BRA    *+2       3,3
854  19BE                FD53
     19BE                        STAZ   PORTB     4,5
     19C0                        NOP    ***
857                      * NOP FOR 2 ** 20, COMMENT FOR 1 MHZ
     19C1                        NOP    2,2
     19C2                        LDAI   (23)      2,2 ***
860                      * 22 FOR 1 MHZ,23 FOR 2 ** 20, 94 FOR 3.579
861  19C4                BK55
     19C4                        DECA   3
863  19C5 26  FD                 BNE    BK55      3
     19C7                        DEX    3,5
865  19C8 26  E4                 BNE    BK66      3,3
     19CA                        LDXZ   XT1
     19CC                        RTS
868
869  19CD                PRALL
     19CD                        LDAI   (RAMSZL)
     19CF                        STAZ   PDCTRL
     19D1                        LDAI   (RAMSZH)
     19D3                        STAZ   PDCTRH
     19D5                        LDAZ   SAVPTR    START AT SAVEPOINTER+2
     19D7                        STAZ   CBASEH
     19D9                        LDAZ   SAVPTR+1
     19DB                        STAZ   CBASEL
     19DD                        JSR    INCGET
879  19E0 20  22                 BRA    FD35
880  19E2                PRNT
     19E2                        LDAZ   DATAST    START AT DATASTART
```

```
                19E4                    STAZ   GBASEH
                19E6                    LDAZ   DATAST+1
                19E8                    STAZ   GBASEL
                19EA                    LDAZ   SAVPTR+1  CALC DATA COUNT
                19EC                    SUBAZ  DATAST+1
                19EE                    STAZ   PDCTRL
                19F0                    LDAZ   SAVPTR
                19F2                    SBCAZ  DATAST
                19F4                    STAZ   PDCTRH .
    891         19F6 2A   0C            BPL    FD35      BR IF POS
                19F8                    LDAZ   PDCTRL    WRAP AROUND 0
                19FA                    ADDAI  (RAMSZL)
                19FC                    STAZ   PDCTRL
                19FE                    LDAZ   PDCTRH
                1A00                    ADCAI  (RAMSZH)
                1A02                    STAZ   PDCTRH
    898         1A04            FD35
                1A04                    LSRZ   PDCTRH    CNV TO DATA POINT COUNT
                1A06                    RORZ   PDCTRL
                1A08                    LDAI   (1)
                1A0A                    STAZ   DAYNUM
    903         1A0C            NXTPG
                1A0C                    LDXI   (2)
                1A0E                    JSR    CRLF
                1A11                    LDXI   (5)
                1A13                    JSR    SPACE
                1A16                    LDXI   (M1-MSGS) MINERAL
                1A18                    JSR    OUTSTR
                1A1B                    LDXI   (M2-MSGS) DIESEL
                1A1D                    LDAZ   PORTB     ASBES BIT
    912         1A1F 2B   02            BMI    FD26
                1A21                    LDXI   (M3-MSGS) ASBESTOS
    914         1A23            FD26
                1A23                    JSR    OUTSTR
                1A26                    LDXI   (M4-MSGS) DUS..ORT
                1A28                    JSR    OUTSTR
                1A2B                    LDAI   (66)      PAGE POSN
                1A2D                    SUBAZ  COLNUM
                1A2F                    TAX
                1A30                    JSR    SPACE
                1A33                   .LDXI   (M5-MSGS) PAGE
                1A35                    JSR    OUTSTR
                1A38                    LDAZ   DAYNUM
                1A3A                    STAZ   TMPLO
                1A3C                    CLRZ   TMPHI
                1A3E                    JSR    BINBCD
                1A41                    LDXI   (5)
                1A43                    JSR    ASCOUT
                1A46                    LDXI   (3)
                1A48                    JSR    CRLF
                1A4B                    LDXI   (5)
                1A4D                    JSR    SPACE
                1A50                    LDXI   (M6-MSGS) D.HH.MM
                1A52                    JSR    OUTSTR
```

```
      1A55                        CLRZ   PRHRCT    HOUR NUMBER
  937 1A57              BK91
      1A57                        LDXI   (3)
      1A59                        JSR    SPACE
      1A5C                        LDAZ   DAYNUM
      1A5E                        ADDAI  ('0-1)
      1A60                        JSR    OUTCHR
      1A63                        LDAI   ('.)
      1A65                        JSR    OUTCHR
      1A68                        CLRZ   TMPHI
      1A6A                        LDAZ   PRHRCT
      1A6C                        STAZ   TMPLO
      1A6E                        JSR    BNBCD2    KEEP LEADING ZEROES
      1A71                        LDXI   (4)       LAST 2 CHRS
      1A73                        JSR    ASCOUT
      1A76                        LDXI   (M8-MSGS) ".00"
      1A78                        JSR    OUTSTR
      1A7B                        LDAZ   PRHRCT
      1A7D                        ADDAI  (4)
      1A7F                        STAZ   PRHRCT
      1A81                        CMPAI  (24)
  957 1A83 26   D2                BNE    BK91
      1A85                        LDXI   (2)
      1A87                        JSR    CRLF
      1A8A                        CLRZ   MOD4
  961 1A8C              NXTHR
      1A8C                        LDXI   (7)       HEADER 1
      1A8E                        JSR    SPACE
      1A91                        LDAI   ('+)
      1A93                        JSR    OUTCHR
      1A96                        LDAZ   MOD4
      1A98                        ADDAI  ('0)
      1A9A                        JSR    OUTCHR
      1A9D                        LDXI   (M8-MSGS) ".00"
      1A9F                        JSR    OUTSTR
      1AA2                        LDXI   (3)
      1AA4                        JSR    SPACE
      1AA7                        JSR    DLINE     REST OF LINE
      1AAA                        JSR    GR3       2 MORE DATA LINES
      1AAD                        LDAI   (3)
      1AAF                        STAZ   MOD3
  977 1AB1              BK87
      1AB1                        LDXI   (11)      HEADER TYPE 2
      1AB3                        JSR    SPACE
      1AB6                        LDAI   ('-)
      1AB8                        JSR    OUTCHR
      1ABB                        LDXI   (3)
      1ABD                        JSR    SPACE
      1AC0                        JSR    DLINE     REST OF LINE
      1AC3                        JSR    GR3       2 MORE DATA LINES
      1AC6                        DECZ   MOD3
  987 1AC8 26   E7                BNE    BK87
      1ACA                        LDXI   (1)
      1ACC                        JSR    CRLF
```

```
                1ACF
                1AD1
                1AD3
     993        1AD5 26    B5          INCZ    MOD4
                1AD7                   LDAZ    MOD4
                1AD9                   CMPAI   (4)         END OF PAGE ?
                1ADC                   BNE     NXTHR       BR IF NOT
                1ADE                   LDAI    (FF)
                1AE0                   JSR     OUTCHR
                1AE2                   LDAZ    PDCTRL      ADJ DATA DNCTR
                1AE4                   SUBAI   (240)       48*5
                1AE6                   STAZ    PDCTRL
                1AE8                   LDAZ    PDCTRH
    1003        1AEA 2B    1F          SBCAI   (0)
                1AEC                   STAZ    PDCTRH
                1AEE                   TSTZ    PDCTRH
                1AF0                   BMI     FD36        BR IF DONE
                1AF2                   INCZ    DAYNUM
                1AF4                   LDAZ    GBASEL      ADJ PAGE STRT ADDR
                1AF6                   ADDAI   (224)       480 LO PART
                1AF8                   STAZ    GBASEL
    1011        1AFA 25    0A          LDAZ    GBASEH
                1AFC                   ADCAI   (1)         480 HI PART
                1AFE                   CMPAI   (RAMEND)    PAST RAM END ?
                1B00                   BLO     FD41        BR IF NOT
                1B02                   LDAZ    GBASEL
                1B04                   SUBAI   (RAMSZL)
    1017        1B06                   STAZ    GBASEL
                1B06                   LDAZ    GBASEH
                1B08                   SBCAI   (RAMSZH)
    1020        1B0B    FD41
                1B0B                   STAZ    GBASEH
    1022                               JMP     NXTPG
    1023        1B0E    FD36
                1B0E                   JMP     RUN
                1B10
                1B13    GR3
                1B16                   LDXI    (15)        HEADER TYPE 3
                1B18                   JSR     SPACE
                1B1B                   JSR     DLINE       REST OF LINE
                1B1E                   LDXI    (15)        HEADER TYPE 3
    1031                               JSR     SPACE
    1032        1B1F                   JSR     DLINE       REST OF LINE
                1B1F                   RTS
                1B21
                1B23    INCGET
                1B25                   LDAZ    GBASEL      BUMP LO POINTER
                1B27                   ADDAI   (2)
                1B29                   STAZ    GBASEL
    1039        1B2B 26    06          LDAZ    GBASEH
                1B2D                   ADCAI   (0)
                1B2F                   CMPAI   (RAMEND)    CHK FOR END OF RAM
                1B31                   BNE     FD23        BR IF NOT
    1043        1B33                   LDAI    (RAMSTL)    RE-INIT TO STRT
                                       STAZ    GBASEL
                                       LDAI    (RAMSTH)
                                FD23
```

```
                1B33                    STAZ   GBASEH
                1B35                    RTS
          1046
          1047                  *+ DLINE: PRINT A LINE OF DATA
          1048
          1049  1B36            DLINE
                1B36                    LDAI   (6)        6 ITEMS PER LINE
                1B38                    STAZ   DATAC
                1B3A                    LDAZ   GBASEL.    COPY TO GETPTR
                1B3C                    STAZ   GETPTR+1
                1B3E                    LDAZ   GBASEH
                1B40                    STAZ   GETPTR
          1056  1B42            BK88
                1B42                    LDAZ   GETPTR     CHECK POINTER
                1B44                    CMPAI  (RAMEND)   PAST RAM END ?
          1059  1B46 25   0C            BLO    FD37       BR IF NOT
                1B48                    LDAZ   GETPTR+1
                1B4A                    SUBAI  (RAMSZL)
                1B4C                    STAZ   GETPTR+1
                1B4E                    LDAZ   GETPTR
                1B50                    SBCAI  (RAMSZH)
                1B52                    STAZ   GETPTR
          1066  1B54            FD37
                1B54                    TSTZ   PDCTRH     TOO FAR GONE ?
          1068  1B56 2B   31            BMI    FD45       BR IF YES
          1069  1B58 26   04            BNE    FD77       BR IF NO
                1B5A                    TSTZ   PDCTRL     MAYBE, CHK LSB
          1071  1B5C 27   2B            BEQ    FD45       BR IF YES
          1072  1B5E            FD77
                1B5E                    JSR    GETRTN     MODIFYABLE CODE
                1B61                    CMPAI  ($FF)      INVALID ?
          1075  1B63 27   26            BEQ    FD38       BR IF YES
                1B65                    STAZ   TMPLO      CNV TO ASCII
                1B67                    CLRZ   TMPHI
                1B69                    JSR    BINBCD
                1B6C                    LDXI   (3)
                1B6E                    JSR    ASCOUT     PRINT IT
                1B71                    LDAI   ($2C)      COMMA
                1B73                    JSR    OUTCHR
                1B76                    INCZ   GETPTR+1   GET 2ND BYTE
                1B78                    JSR    GETRTN     MODIFYABLE CODE
                1B7B                    STAZ   TMPLO      CNV IT
                1B7D                    CLRZ   TMPHI
                1B7F                    JSR    BINBCD
                1B82                    LDXI   (3)
                1B84                    JSR    ASCOUT     PRINT IT TOO
          1090  1B87 20   09            BRA    FD40       AROUND NEXT SECTN
          1091  1B89            FD45
                1B89                    CLRZ   DAYNUM     AT OR PAST SAVE PTR
          1093  1B8B            FD38
                1B8B                    INCZ   GETPTR+1   IGNORE 2ND BYTE
                1B8D                    LDXI   (M9-MSGS)  INVALID DATA MSG
                1B8F                    JSR    OUTSTR     PRINT IT
          1097  1B92            FD40
```

```
                1B92                        LDAZ   GETPTR+1  SET FOR NEXT DATA
                1B94                        ADDAI  (95)      48*2-1
                1B96                        STAZ   GETPTR+1  WILL CHK FOR
                1B98                        LDAZ   GETPTR    WRAPAROUND ETC AT
                1B9A                        ADCAI  (0)       TOP OF LOOP
                1B9C                        STAZ   GETPTR
                1B9E                        LDAZ   PDCTRL    DEC DATA DNCTR
                1BA0                        SUBAI  (48)
                1BA2                        STAZ   PDCTRL
                1BA4                        LDAZ   PDCTRH
                1BA6                        SBCAI  (0)
                1BA8                        STAZ   PDCTRH
                1BAA                        DECZ   DATAC
1111            1BAC 27   08                BEQ    FD44      BR IF DONE
                1BAE                        LDXI   (3)
                1BB0                        JSR    SPACE
                1BB3                        JMP    BK88      LOOP BACK
1115            1BB6              FD44
                1BB6                        LDAZ   PDCTRL    DEC DATA DNCTR
                1BB8                        ADDAI  (31)      48*6-1 LO PRT
                1BBA                        STAZ   PDCTRL
                1BBC                        LDAZ   PDCTRH
                1BBE                        ADCAI  (1)       HI PRT
                1BC0                        STAZ   PDCTRH
                1BC2                        JSR    INCGET
                1BC5                        LDXI   (1)
                1BC7                        JSR    CRLF
                1BCA                        RTS
1126
1127            1BCB              SPACE
                1BCB                        LDAI   ($20)
                1BCD                        JSR    OUTCHR
                1BD0                        INCZ   COLNUM
                1BD2                        DEX
1132            1BD3 26   F6                BNE    SPACE
                1BD5                        RTS
1134
1135            1BD6              OUTSTR
                1BD6                        LDA    MSGS,X
                1BD9                        CMPAI  (4)
1138            1BDB 26   01                BNE    FD24
                1BDD                        RTS
1140            1BDE              FD24
                1BDE                        JSR    OUTCHR
                1BE1                        INX
                1BE2                        INCZ   COLNUM
1144            1BE4 20   F0                BRA    OUTSTR
1145
1146            1BE6              ASCOUT
                1BE6                        LDA    ASCBUF,X
                1BE9                        CMPAI  (4)
1149            1BEB 26   01                BNE    FD25
                1BED                        RTS
1151            1BEE              FD25
```

```
                1BEE                    JSR     OUTCHR
                1BF1                    INX
                1BF2                    INCZ    COLNUM
          1155  1BF4 20   F0            BRA     ASCOUT
          1156
          1157  1BF6              CRLF
                1BF6                    JSR     ENDCHK
                1BF9                    LDAI    (CR)
                1BFB                    JSR     OUTCHR.
                1BFE                    LDAI    (LF)
                1C00                    JSR     OUTCHR
                1C03                    DEX     REPEAT      PER "X"
          1164  1C04 26   F0            BNE     CRLF
                1C06                    CLRZ    COLNUM
                1C08                    RTS
          1167
          1168  1C09              WSUB
                1C09                    WAIT
                1C0A                    RTS
          1171
          1172  1C0B              TMRIRQ
                1C0B                    LDAZ    TMRC
                1C0D                    ANDAI   ($7F)       CLR TMR IRQ FLG
                1C0F                    STAZ    TMRC        AND ENABLE MORE
                1C11                    RTI
          1177
          1178                  ;+ CONINP: INPUT 8 CONSTANTS
          1179  1C12              CONINP
                1C12                    LDAI    (7)         #0-7
                1C14                    STAZ    HTMP
          1182  1C16              BK83
                1C16                    LDAZ    HTMP        CONST NO.
                1C18                    ADDAI   ($8)
                1C1A                    JSR     ADC
                1C1D                    LDAZ    HTMP
                1C1F                    ASLA    *2
                1C20                    TAX
                1C21                    LDAZ    ADCH        SAVE DATA
                1C23                    STA     CONMEM,X
                1C26                    LDAZ    ADCL
                1C28                    STA     CONMEM+1,X
                1C2B                    DECZ    HTMP
          1194  1C2D 2A   E7            BPL     BK83        LOOP TILL ALL DONE
          1195
          1196                  ; ADJUST "E" FOR DIESEL-ASBEST
          1197
                1C2F                    LDAZ    ADCH        COPY CONMEM(0) TO M2
                1C31                    STAZ    M2DQH
                1C33                    LDAZ    ADCL
                1C35                    STAZ    M2DQL
                1C37                    TSTZ    PORTB       CHK ASBES-DIESEL BIT
          1203  1C39 2B   0A            BMI     FD27        BR IF DIESEL
                1C3B                    LDAI    (9)         2550 HI PRT
                1C3D                    STAZ    M1DSH
```

```
                1C3F                    LDAI    (246)       2550 LO PRT
                1C41                    STAZ    M1DSL
1208            1C43 20   06            BRA     FD28
1209            1C45            FD27
                1C45                    CLRZ    M1DSH       85 HI PART
                1C47                    LDAI    (85)        85 LO PRT
                1C49                    STAZ    M1DSL
1213            1C4B            FD28
                1C4B                    JSR     MULT .
                1C4E                    LDAI    (10)        DIV BY 64
                1C50                    JSR     SHIFT
                1C53                    LDAZ    MPDDH       SAVE DATA
                1C55                    STAZ    CONMEM+0
                1C57                    LDAZ    MPDD2H
                1C59                    STAZ    CONMEM+1
                1C5B                    ASLZ    CONMEM+7    ADJUST "F"
                1C5D                    ROLZ    CONMEM+6
                1C5F                    ASLZ    CONMEM+7
                1C61                    ROLZ    CONMEM+6
                1C63                    LDAZ    CONMEM+3    CNV OFFSET 1 TO BIPOLAR
                1C65                    SUBAZ   CONMEM+15
                1C67                    STAZ    CONMEM+3
                1C69                    LDAZ    CONMEM+2
                1C6B                    SBCAZ   CONMEM+14
                1C6D                    STAZ    CONMEM+2
                1C6F                    ASLZ    CONMEM+3    DOUBLE IT
                1C71                    ROLZ    CONMEM+2
                1C73                    LDAZ    CONMEM+9    CNV OFFSET 2 TO BIPOLAR
                1C75                    SUBAZ   CONMEM+15
                1C77                    STAZ    CONMEM+9
                1C79                    LDAZ    CONMEM+8
                1C7B                    SBCAZ   CONMEM+14
                1C7D                    STAZ    CONMEM+8
                1C7F                    ASLZ    CONMEM+9    DOUBLE IT TOO
                1C81                    ROLZ    CONMEM+8
                1C83                    RTS
1242
1243                            ;+ MESURE: INPUT DATA ; CALC
1244
1245            1C84            MESURE
                1C84                    LDAZ    PORTB
                1C86                    ORAI    ($2)        45' LED ON
                1C88                    STAZ    PORTB
                1C8A                    LDAI    (2)         REF PC
                1C8C                    JSR     ADC
                1C8F                    LDAZ    ADCH
                1C91                    STAZ    M1DSH
                1C93                    LDAZ    ADCL
                1C95                    STAZ    M1DSL
                1C97                    LDAI    (4)         MAIN PC
                1C99                    JSR     ADC
                1C9C                    LDAZ    PORTB
                1C9E                    ANDAI   ($FD)       45' LED OFF
                1CA0                    STAZ    PORTB
```

```
                1CA2                    LDAZ    ADCH
                1CA4                    STAZ    MPDD2L
                1CA6                    LDAZ    ADCL
                1CA8                    STAZ    MPDDL
                1CAA                    CLRZ    MPDD2H
                1CAC                    CLRZ    MPDDH
                1CAE                    LDAI    (12)        *4096
                1CB0                    JSR     SHIFT
                1CB3                    JSR     DIVIDE
                1CB6                    LDAZ    M2DQH
                1CB8                    STAZ    DATAXH
                1CBA                    LDAZ    M2DQL
                1CBC                    STAZ    DATAXL
                1CBE                    LDAZ    PORTB
                1CC0                    ORAI    ($4)        90' LED ON
                1CC2                    STAZ    PORTB
                1CC4                    LDAI    (3)         REF PC
                1CC6                    JSR     ADC
                1CC9                    LDAZ    ADCH
                1CCB                    STAZ    M1DSH
                1CCD                    LDAZ    ADCL
                1CCF                    STAZ    M1DSL
                1CD1                    LDAI    (5)         MAIN PC
                1CD3                    JSR     ADC
                1CD6                    LDAZ    PORTB
                1CD8                    ANDAI   ($FB)       90' LED OFF
                1CDA                    STAZ    PORTB
                1CDC                    LDAZ    ADCH
                1CDE                    STAZ    MPDD2L
                1CE0                    LDAZ    ADCL
                1CE2                    STAZ    MPDDL
                1CE4                    CLRZ    MPDD2H
                1CE6                    CLRZ    MPDDH
                1CE8                    LDAI    (12)        *4096
                1CEA                    JSR     SHIFT
                1CED                    JSR     DIVIDE
                1CF0                    LDAZ    M2DQH       SAVE Y
                1CF2                    STAZ    DATAYH
                1CF4                    LDAZ    M2DQL
                1CF6                    STAZ    DATAYL
    1300
    1301                        * CALC FOR DIESEL
    1302
                1CF8                    LDAZ    DATAYH      Y TO M1
                1CFA                    STAZ    M1DSH
                1CFC                    LDAZ    DATAYL
                1CFE                    STAZ    M1DSL
                1D00                    LDAZ    CONMEM+0    E TO M2
                1D02                    STAZ    M2DQH
                1D04                    LDAZ    CONMEM+1
                1D06                    STAZ    M2DQL
                1D08                    JSR     MULT
                1D0B                    LDAI    (5)         DIV BY 2048
                1D0D                    JSR     SHIFT
```

```
      1D10                    LDAZ   DATAXL    X-E*Y TO M1
      1D12                    SUBAZ  MPDD2H
      1D14                    STAZ   M1DSL
      1D16                    LDAZ   DATAXH
      1D18                    SBCAZ  MPDDH
      1D1A                    STAZ   M1DSH
      1D1C                    LDAZ   M1DSL     ADD OFFSET
      1D1E                    ADDAZ  CONMEM+3
      1D20                    STAZ   M1DSL     * RESULT MAY BE NEGATIVE
      1D22                    LDAZ   M1DSH
      1D24                    ADCAZ  CONMEM+2
      1D26                    STAZ   M1DSH
      1D28                    LDAZ   CONMEM+4  SCALE1 TO M2
      1D2A                    STAZ   M2DQH
      1D2C                    LDAZ   CONMEM+5
      1D2E                    STAZ   M2DQL
      1D30                    JSR    MULT
      1D33                    LDAI   (4)       DIV BY 4096
      1D35                    JSR    SHIFT
      1D38                    LDAZ   MPDDH     RESULT TO DAC, LCD
      1D3A                    STAZ   DACH
      1D3C                    STAZ   TMPHI
      1D3E                    STAZ   OUTDAT+2
      1D40                    LDA    MPDD2H
      1D43                    STAZ   DACL
      1D45                    STAZ   TMPLO
      1D47                    STAZ   OUTDAT+3
      1D49                    LDAI   (0)       DAC CH0
      1D4B                    JSR    DAC
      1D4E                    JSR    BINBCD
      1D51                    JSR    LCDFMT
1345
      1D54                    LDXI   (4)       MOVE LCD BITS 4 BYTES
1347  1D56              BK27
      1D56                    LDA    OCTMP-1,X
      1D59                    STA    OCTMP+3,X
      1D5C                    DEX
1351  1D5D 26   F7            BNE    BK27
1352
1353                  * REPEAT CALC FOR MINERAL
1354
      1D5F                    LDAZ   DATAYH    Y TO M1
      1D61                    STAZ   M1DSH
      1D63                    LDAZ   DATAYL
      1D65                    STAZ   M1DSL
      1D67                    LDAZ   CONMEM+6  F TO M2
      1D69                    STAZ   M2DQH
      1D6B                    LDAZ   CONMEM+7
      1D6D                    STAZ   M2DQL
      1D6F                    JSR    MULT
      1D72                    LDAI   (5)       DIV BY 2048
      1D74                    JSR    SHIFT
      1D77                    LDAZ   DATAXL    X-F*Y TO M1
      1D79                    SUBAZ  MPDD2H
```

```
                1D7B                    STAZ   M1DSL      * RESULT MAY BE NEGATIVE
                1D7D                    LDAZ   DATAXH
                1D7F                    SBCAZ  MPDDH
                1D81                    STAZ   M1DSH
                1D83                    LDAZ   M1DSL      ADD OFFSET
                1D85                    ADDAZ  CONMEM+9
                1D87                    STAZ   M1DSL
                1D89                    LDAZ   M1DSH
                1D8B                    ADCAZ  CONMEM+8
                1D8D                    STAZ   M1DSH
                1D8F                    LDAZ   CONMEM+10 SCALE 2 TO M2
                1D91                    STAZ   M2DQH
                1D93                    LDAZ   CONMEM+11
                1D95                    STAZ   M2DQL
                1D97                    JSR    MULT
                1D9A                    LDAI   (4)        DIV BY 4096
                1D9C                    JSR    SHIFT
                1D9F                    LDAZ   MPDDH      SAVE TO DAC, LCD, AVERAGER
                1DA1                    STAZ   DACH
                1DA3                    STAZ   TMPHI
                1DA5                    STAZ   OUTDAT+0
                1DA7                    LDAZ   MPDD2H
                1DA9                    STAZ   DACL
                1DAB                    STAZ   TMPLO
                1DAD                    STAZ   OUTDAT+1
                1DAF                    LDAI   (1)        DAC CH 1
                1DB1                    JSR    DAC
                1DB4                    JSR    BINBCD
                1DB7                    JSR    LCDFMT
1397
                1DBA                    JSR    LCDDRV     DRIVE BOTH LCDS
                1DBD                    RTS
1400
1401                            *+ ADC: ENTER W. CHAN NUM 0-15 IN "A".
1402                            * RET W. 0-1023 IN ADCH-ADCL.
1403
1404            1DBE            ADC
                1DBE                    STAZ   TMP1       CH NUM
                1DC0                    CLRZ   ADCH       RET VAL CTR
                1DC2                    CLRZ   ADCL
                1DC4                    LDAI   (3)        1024 PASSES
                1DC6                    STAZ   TMPHI
                1DC8                    LDAI   ($FF)
                1DCA                    STAZ   TMPLO
                1DCC                    LDAI   ($2F)      SOURCE OFF, CH 15
                1DCE                    STAZ   PORTA
1414            1DD0            BK94
                1DD0                    TSTZ   PORTA
1416            1DD2 2B   FC            BMI    BK94
                1DD4                    CLRZ   PORTA      SOURCE ON, CH 0
1418            1DD6            BK95
                1DD6                    TSTZ   PORTA
1420            1DD8 2A   FC            BPL    BK95
                1DDA                    LDAI   ($20)      SOURCE OFF
```

```
      1DDC                          ORAZ   TMP1      CH NUM
      1DDE                          STAZ   PORTA
1424  1DE0                    BK93
      1DE0                          LDAZ   TMP1      CH NUM
      1DE2                          TSTZ   PORTA
1427  1DE4 2B   10                  BMI    FD15      BR IF HI V
      1DE6                          STAZ   PORTA     SOURCE ON
      1DE8                          LDAZ   ADCL      INC ADCVAL
      1DEA                          ADDAI  (1)
      1DEC                          STAZ   ADCL
      1DEE                          LDAZ   ADCH
      1DF0                          ADCAI  (0)
      1DF2                          STAZ   ADCH
1435  1DF4 20   0C                  BRA    FD17
1436  1DF6                    FD15
      1DF6                          ORAI   ($20)     SOURCE OFF
      1DF8                          STAZ   PORTA
1439  1DFA 21   06                  BRN    FD17      13 CYC DELAY
1440  1DFC 21   04                  BRN    FD17
1441  1DFE 21   02                  BRN    FD17
      1E00                          NOP
      1E01                          NOP
1444  1E02                    FD17
      1E02                          LDAZ   TMPLO     DEC TIME CTR
      1E04                          SUBAI  (1)
      1E06                          STAZ   TMPLO
      1E08                          LDAZ   TMPHI
      1E0A                          SBCAI  (0)
      1E0C                          STAZ   TMPHI
1451  1E0E 2A   D0                  BPL    BK93
      1E10                          JSR    MON
      1E13                          JSR    ENDCHK
      1E16                          RTS
1455
1456                          ;+ DAC: ENTER W. CH NUM 0-1 IN "A" AND
1457                          ; DATA IN DACH-DACL.
1458
1459  1E17                    DAC
      1E17                          STAZ   TMP1
      1E19                          LDAI   ($60)     DISCH. CH 0
      1E1B                          STAZ   PORTA
      1E1D                          LDAI   (10)      DISCH TIME
      1E1F                          JSR    DLY
      1E22                          LDAI   (0)       NEG DACVAL
      1E24                          SUBAZ  DACL
      1E26                          STAZ   DACL
      1E28                          LDAI   (0)
      1E2A                          SBCAZ  DACH
      1E2C                          STAZ   DACH
1471  1E2E 2A   10                  BPL    FD18      NO SLEW IF WAS 0 OR LESS
      1E30                          LDAZ   DACL
      1E32                          CLRZ   PORTA     SLEW UP
1474  1E34                    BK92
      1E34                          INCA   TIMING    LOOP
```

```
1476  1E35 27  05            BEQ   FD19      14 CYC
      1E37                   NOP
1478  1E38 21  FA            BRN   BK92
1479  1E3A 20  F8            BRA   BK92
1480  1E3C              FD19
      1E3C                   INCZ  DACH
1482  1E3E 2B  F4            BMI   BK92      LOOP END
1483  1E40              FD18
      1E40                   LDAI  ($20).    SLEW OFF
      1E42                   STAZ  PORTA
      1E44                   LDAZ  TMP1      CH NUM
      1E46                   ORAI  ($30)     SEL OUT CH:
      1E48                   STAZ  PORTA
      1E4A                   LDAI  (10)      SETTLE TIME
      1E4C                   JSR   DLY
      1E4F                   LDAI  ($20)     IDLE
      1E51                   STAZ  PORTA
      1E53                   RTS
1494
1495                  $+ BNBCD2: CONVERT 2 BYTES IN TMPHI-TMPLO
1496                  $ TO SIGN + 5 ASCII DIG'S + EOF ($4) IN ASCBUF
1497
1498                  $ ACCOUNT FOR SIGN
1499
1500  1E54            BNBCD2
      1E54                   LDAI  ($20)     MAY BE "+" INSTEAD
      1E56                   STAZ  ASCBUF+0
      1E58                   TSTZ  TMPHI
1504  1E5A 2A  10            BPL   FD10      BR IF "+"
      1E5C                   LDAI  (0)       IT'S MINUS: SUTRACT FROM 0
      1E5E                   SUBAZ TMPLO
      1E60                   STAZ  TMPLO
      1E62                   LDAI  (0)
      1E64                   SBCAZ TMPHI
      1E66                   STAZ  TMPHI
      1E68                   LDAI  ('-)      ANDA UPDATE ASCBUF
      1E6A                   STAZ  ASCBUF+0
1513  1E6C              FD10
1514
1515                  $ CONVERT BY SUCESSIVE SUBATRACTION
1516
      1E6C                   LDXI  (0)
      1E6E                   STXZ  XT1
      1E70                   STXZ  XT2
1520  1E72              BK99
      1E72                   LDAI  ('0-1)
      1E74                   STAZ  TMP1
      1E76                   LDXZ  XT1       BCDTBL
1524  1E78              BK98
      1E78                   INCZ  TMP1
      1E7A                   LDAZ  TMPLO     16 BIT SUTRACT
      1E7C                   SUBA  BCDTBL+1,X
      1E7F                   STAZ  TMPLO
      1E81                   LDAZ  TMPHI
```

```
                1E83                    SBCA    BCDTBL,X
                1E86                    STAZ    TMPHI
1532            1E88 24   EE            BCC     BK98        REPEATED
                1E8A                    LDAZ    TMPLO       ADD BACK ONCE
                1E8C                    ADDA    BCDTBL+1,X
                1E8F                    STAZ    TMPLO
                1E91                    LDAZ    TMPHI
                1E93                    ADCA    BCDTBL,X
                1E96                    STAZ    TMPHI.
                1E98                    INX     BCDTBL      PTR
                1E99                    INX
                1E9A                    STXZ    XT1
                1E9C                    LDXZ    XT2         GET ASCBUF PTR
                1E9E                    LDAZ    TMP1
                1EA0                    STA     ASCBUF+1,X SAVE DATA
                1EA3                    INX
                1EA4                    STXZ    XT2         ASCPTR
                1EA6                    CPXI    (5)
1548            1EA8 26   C8            BNE     BK99
                1EAA                    LDAI    (4)         ADD TERMINATOR
                1EAC                    STAZ    ASCBUF+6
                1EAE                    RTS
1552
1553                            ;+ BINBCD: WITH LEADING 0 SUPRESSION
1554
1555            1EAF            BINBCD
                1EAF                    JSR     BNBCD2
                1EB2                    LDXI    (1)
1558            1EB4            BK89
                1EB4                    LDA     ASCBUF,X
                1EB7                    CMPAI   ('0)
1561            1EB9 26   0A            BNE     FD11        DONE IF NON-ZERO
                1EBB                    LDAI    ($20)       BLANK
                1EBD                    STA     ASCBUF,X
                1EC0                    INX
                1EC1                    CPXI    (5)         DON'T BLANK THE LSD
1566            1EC3 26   EF            BNE     BK89
1567            1EC5            FD11
                1EC5                    RTS
1569
1570                            ;+ LCDFMT: CONVERT 4 ASCII LSD'S IN ASCBUF TO 4
1571                            ; BYTES OF SEGMENT BITS IN OCTMP, SHOW MINUS USING
1572                            ; LEFT DECIMAL PT
1573
1574            1EC6            LCDFMT
                1EC6                    LDXI    (0)
                1EC8                    STXZ    XT1
1577            1ECA            BK97
                1ECA                    LDXZ    XT1
                1ECC                    CLR     OCTMP,X
                1ECE                    LDA     ASCBUF+2,X
                1ED1                    CMPAI   ($20)       BLANK
1582            1ED3 27   0B            BEQ     FD13
                1ED5                    SUBAI   ('0)
```

```
                1ED7                    TAX
                1ED8                    LDA     SEG7,X
                1EDB                    LDXZ    XT1
                1EDD                    STA     OCTMP,X
1588            1EE0            FD13
                1EE0                    INX
                1EE1                    STXZ    XT1
                1EE3                    CPXI    (4)
1592            1EE5 26  E3             BNE     BK97
                1EE7                    LDAZ    ASCBUF      SIGN POSN
                1EE9                    CMPAI   ('-)
1595            1EEB 26  06             BNE     FD14
                1EED                    LDAZ    OCTMP+0
                1EEF                    ORAI    ($01)       1ST DECIMAL PT
                1EF1                    STAZ    OCTMP+0
1599            1EF3            FD14
                1EF3                    RTS
1601
1602                            * OUTPUT 64 BITS TO LCD FROM OCTMP
1603
1604            1EF4            LCDDRV
                1EF4                    LDAI    (64)
                1EF6                    STAZ    HTMP
                1EF8                    LDAZ    PORTA
1608            1EFA            BK96
                1EFA                    ANDAI   ($FE)       DATA OFF
                1EFC                    RORZ    OCTMP
                1EFE                    RORZ    OCTMP+1
                1F00                    RORZ    OCTMP+2
                1F02                    RORZ    OCTMP+3
                1F04                    RORZ    OCTMP+4
                1F06                    RORZ    OCTMP+5
                1F08                    RORZ    OCTMP+6
                1F0A                    RORZ    OCTMP+7
1618            1F0C 24  02             BCC     FD12
                1F0E                    ORAI    ($01)       DATA ON
1620            1F10            FD12
                1F10                    STAZ    PORTA
                1F12                    ORAI    ($02)       CLK HI
                1F14                    STAZ    PORTA
                1F16                    ANDAI   ($FD)       CLK LO
                1F18                    STAZ    PORTA
                1F1A                    DECZ    HTMP
1627            1F1C 26  DC             BNE     BK96
                1F1E                    LDAZ    PORTB
                1F20                    ORAI    ($01)       LOAD HI
                1F22                    STAZ    PORTB
                1F24                    ANDAI   ($FE)       LOAD LO
                1F26                    STAZ    PORTB
                1F28                    RTS
1634
1635                            *+ DLY: DELAY PER "A": X DESTROYED
1636
1637            1F29            DLY
```

LDAZ OCTMP+3
ORAI #01
STAZ OCTMP+3

* LAST DEC. PT. ON

```
1638  1F29                BK86
      1F29                        LDXI   (20)
1640  1F2B                BK90
      1F2B                        DEX
1642  1F2C 26   FD                BNE    BK90
      1F2E                        DECA
1644  1F2F 26   F8                BNE    BK86
      1F31                        RTS
1646
1647                      ;+ MULT: MPDD = M1DS * M2DQ
1648                      ; M1 MAY BE SIGNED: M2 IS UNSIGNED
1649
1650  1F32                MULT
      1F32                        LDAI   (16)       LOOP COUNT
      1F34                        STAZ   MDCTR
      1F36                        CLRZ   MPDDH      CLR HI PRODUCT
      1F38                        CLRZ   MPDDL
      1F3A                        LDAZ   M2DQH      COPY M2 TO
      1F3C                        STAZ   MPDD2L     LO PRODUCT
      1F3E                        LDAZ   M2DQL
      1F40                        STAZ   MPDDL
      1F42                        RORA   LSB        TO CARRY
1660  1F43                BK84
1661  1F43 24   0C                BCC    FD20       BR IF NO CARRY
      1F45                        LDAZ   M1DSL      ADD M1 TO HI PRODUCT
      1F47                        ADDAZ  MPDD2H
      1F49                        STAZ   MPDD2H
      1F4B                        LDAZ   M1DSH
      1F4D                        ADCAZ  MPDDH
      1F4F                        STAZ   MPDDH
1668  1F51                FD20
      1F51                        LDAZ   M1DSH      SIGN OF M1
      1F53                        ASLA   TO         CARRY
      1F54                        RORZ   MPDDH      ROTATE PRODUCT RIGHT
      1F56                        RORZ   MPDD2H
      1F58                        RORZ   MPDD2L
      1F5A                        RORZ   MPDDL
      1F5C                        DECZ   MDCTR
1676  1F5E 26   E3                BNE    BK84       LOOP FOR 16 BITS
      1F60                        RTS
1678
1679                      ;+ DIVIDE: M2DQ = MPDD / M1DS:
1680                      ; UNSIGNED
1681
1682  1F61                DIVIDE
      1F61                        LDAI   (16)
      1F63                        STAZ   MDCTR
1685  1F65                BK81
      1F65                        ASLZ   MPDDL      SHIFT DIVIDEND LEFT
      1F67                        ROLZ   MPDD2L
      1F69                        ROLZ   MPDD2H
      1F6B                        ROLZ   MPDDH
      1F6D                        LDAZ   MPDD2H     SUUBTR DIVISOR FROM PRODUCT
      1F6F                        SUBAZ  M1DSL
```

```
                1F71                        STAZ    MPDD2H
                1F73                        LDAZ    MPDDH
                1F75                        SBCAZ   M1DSH
                1F77                        STAZ    MPDDH
    1696        1F79 24   0F                BCC     FD21        BR IF NO BORROW
                1F7B                        LDAZ    MPDD2H      BORROW: PLUS IT BACK
                1F7D                        ADDAZ   M1DSL
                1F7F                        STAZ    MPDD2H
                1F81                        LDAZ    MPDDH
                1F83                        ADCAZ   M1DSH
                1F85                        STAZ    MPDDH
                1F87                        CLC
    1704        1F88 20   01                BRA     FD22
    1705        1F8A                FD21
                1F8A                        SEC
    1707        1F8B                FD22
                1F8B                        ROLZ    M2DQL       SHIFT QUOTIENT
                1F8D                        ROLZ    M2DQH
                1F8F                        DECZ    MDCTR       LOOP 16 TIMES
    1711        1F91 26   D2                BNE     BK81
                1F93                        RTS
    1713
    1714                            *+ SHIFT: MPDD SHIFTED LEFT PER
    1715                            * COUNT IN "A".
    1716
    1717        1F94                SHIFT
                1F94                        STAZ    MDCTR
    1719        1F96                BK80
                1F96                        ASLZ    MPDDL       SHIFT DIVIDEND LEFT
                1F98                        ROLZ    MPDD2L
                1F9A                        ROLZ    MPDD2H
                1F9C                        ROLZ    MPDDH
                1F9E                        DECZ    MDCTR       LOOP N TIMES
    1725        1FA0 26   F4                BNE     BK80
                1FA2                        RTS

0 ERROR(S) DETECTED
```

SYMBOL TABLE:

ADC	1DBE	ADCH	0038	ADCL	0039	ASCBUF	0058	ASCOUT	1BE6
AVGCLC	1907	AVGDAT	0044	BCDTBL	1816	BINBCD	1EAF	BK27	1D56
BK55	19C4	BK66	19AE	BK68	18D2	BK71	18A4	BK72	192A
BK77	19A8	BK79	187F	BK80	1F96	BK81	1F65	BK82	188F
BK83	1C16	BK84	1F43	BK85	1909	BK86	1F29	BK87	1AB1
BK88	1B42	BK89	1EB4	BK90	1F2B	BK91	1A57	BK92	1E34
BK93	1DE0	BK94	1DD0	BK95	1DD6	BK96	1EFA	BK97	1ECA
BK98	1E78	BK99	1E72	BNBCD2	1E54	COLDB	1870	COLNUM	0030
CONINP	1C12	CONMEM	0048	CR	000D	CRLF	1BF6	DAC	1E17
DACH	003A	DACL	003B	DATAC	0034	DATAST	002E	DATAXH	003C
DATAXL	003D	DATAYH	003E	DATAYL	003F	DAYNUM	0031	DIVIDE	1F61
DLINE	1B36	DLY	1F29	ENDCHK	186F	EXPIO	0000	FD10	1E6C
FD11	1EC5	FD12	1F10	FD13	1EE0	FD14	1EF3	FD15	1DF6
FD17	1E02	FD18	1E40	FD19	1E3C	FD20	1F51	FD21	1F8A
FD22	1F8B	FD23	1B33	FD24	1BDE	FD25	1BEE	FD26	1A23
FD27	1C45	FD28	1C4B	FD29	1924	FD31	1979	FD32	18C5
FD33	18CC	FD34	1951	FD35	1A04	FD36	1B0B	FD37	1B54
FD38	1B8B	FD40	1B92	FD41	1B06	FD44	1BB6	FD45	1B89
FD46	188D	FD47	1957	FD48	1952	FD49	199C	FD50	199A
FD52	19BA	FD53	19BE	FD77	1B5E	FF	000C	GBASEH	0037
GBASEL	0038	GETPTR	0011	GETRTN	0010	GR3	1B0E	HTMP	0023
INCGET	1B1F	LCDDRV	1EF4	LCDFMT	1EC6	LF	000A	M1	1820
M1DSH	0025	M1DSL	0026	M2	1829	M2DQH	0027	M2DQL	0028
M3	1830	M4	1839	M5	184E	M6	1854	M7	185C
M8	1862	M9	1866	MDCTR	0024	MESURE	1C84	MOD3	0032
MOD4	0033	MOD5	002D	MODCOD	1800	MON	186E	MPDD2H	002A
MPDD2L	002B	MPDDH	0029	MPDDL	002C	MSGS	1820	MULT	1F32
NXTHR	1A8C	NXTPG	1A0C	OCTMP	0030	OUTCHR	199D	OUTDAT	0040
OUTSTR	1BD6	PDCTRH	0039	PDCTRL	003A	PORTA	0000	PORTB	0001
PORTDA	0004	PORTDB	0005	PRALL	19CD	PRHRCT	003B	PRNDAT	0035
PRNT	19E2	PWRCHK	0018	PWRDAT	1808	PZBASE	0000	RAM	0000
RAMEND	0018	RAMSTH	0008	RAMSTL	0002	RAMSZH	000F	RAMSZL	00FE
ROM	1800	RUN	18DA	RUNLOP	18DE	SAVINC	1965	SAVPTR	0015
SAVRTN	0014	SEG7	180C	SHIFT	1F94	SPACE	1BCB	SPTINC	197C
TEST	18ED	TMP1	0022	TMPHI	001C	TMPLO	001D	TMRC	0009
TMRD	0008	TMRIRQ	1C0B	TSTLOP	18F9	WASPWR	18B8	WSUB	1C09
XT1	001E	XT2	0020						